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BUREAU OF WATER AND WASTEWATER
WATER & WASTEWATER ENGINEERING DIVISION

Patapsco Sewershed Evaluation Study Plan
Project #1041

Model Development and Calibration Report

Sanitary Sewer Overflow Consent Decree
Civil Action No. JFM-02-1524

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EXECUTIVE SUMMARY

As part of Baltimore City Project No. 1041, Whitman, Requardt & Associates, LLP (WR&A) has developed a hydraulic model of the Patapsco sewershed within the City of Baltimore. This model has been calibrated for both dry weather and wet weather conditions utilizing data from 17 flow monitoring sites and three rain gauge stations. This report outlines the development of the hydraulic model and its calibration. This model meets the requirements of the Consent Decree (CD) agreed upon between the City, the United States Environmental Protection Agency and the Maryland Department of the Environment.

The flow monitoring period extended from May 9, 2006 to May 18, 2007. Ten of the meters have stayed in place beyond this period. In addition to the three rain gauges, rainfall data has also been obtained from a Doppler Radar Rainfall Analysis. The flow meters used are area-velocity flow meters designed to measure flow in sanitary sewer pipes under free-flow and surcharged conditions. All 17 flow meters have been analyzed using the Sliicer.com software. Data derived from the Sliicer.com software includes: weekday and weekend diurnal peaking factors; wastewater production rates; base infiltration; wet weather flow volume (RDII); capture coefficients; and initial loss values.

The modeling software selected for this project is InfoWorks CS, by Wallingford Software, Ltd. As of the date of this report, the most recent version is InfoWorks CS 10.0.3 As required by the CD, the hydraulic model includes all major gravity lines equal to or greater than 10-inches in diameter, 8-inch sewers that connect between 10-inch and greater sewers or are necessary for hydraulic continuity, major wastewater pumping stations and associated force mains and related appurtenances. The model also includes all manholes, junctions, and structures along modeled sewer lines and all control structures existing in the system.

The City's wastewater geodatabase was used as the primary source of information for creating and populating the pipes and nodes network of the InfoWorks hydraulic model. Manhole inspection data, CCTV information, surveys of manhole rim elevations, and review of City engineering record documents were also utilized to make editing changes and enhancements to the City's wastewater GIS and the model network. The GIS data for the hydraulic model was exported into the InfoWorks software. The hydraulic model was checked within InfoWorks for errors, connectivity and other discrepancies.

The Patapsco sewershed has been divided into sub-sewersheds or flow monitoring basins. These basins have been incorporated into the InfoWorks model as subcatchments. All of the sub-sewersheds have been further divided into multiple subcatchments to more accurately represent increasing flows as they accumulate and proceed downstream in the model network, and to create appropriate flow input locations. Subcatchments were generally created to meet or approach the subcatchment size recommendations in the Baltimore Sewer Evaluation Standards Manual (BaSES).

Sources of data used in determining the dry weather flows include: rainfall/flow monitoring data; the City's database of water consumption records; population estimates; estimates of tributary collection system (i.e., linear footage of sewers) to each flow monitor; and estimates of the tributary sewershed area to each flow monitor. The flow analyses performed using the Sliicer.com software provides estimates at each flow monitoring site of the components of the dry weather flow, specifically the average base flow (BSF) and the groundwater infiltration (GWI) rate. The BSF is then estimated as the dry weather flow rate less the GWI estimate. In cases where negative GWI was calculated, the GWI has been estimated as a percentage of the BSF. These values were validated prior to loading flows into the InfoWorks model.

The Sliicer.com analyses yield average daily dry weather flow hydrographs for each monitoring basin for both weekdays and weekends. This data was then used to develop hourly diurnal peaking factors for weekdays and weekends. This was done by subtracting the GWI from the hourly values of the dry weather flow hydrographs and then dividing by the average BSF.

The approach to simulating wet weather flow uses the SWMM RUNOFF routines in InfoWorks CS as a synthetic storm hydrograph generator. Simulating rainfall-dependent infiltration and inflow (RDII) using SWMM RUNOFF within InfoWorks requires the specification of catchment characteristics that will result in rational RDII estimates. The parameters specified are: area; R-value; depression storage; width; slope; and overland flow routing coefficient.

The RDII volume versus rainfall depth plot for each monitoring site has been developed using Sliicer.com software. In addition, Sliicer.com also develops the best-fit linear regression line to the data and the corresponding equation for the regression line, as well as the R-Value, which is proportional to the slope of the regression line. Twenty six storms during the metering period met the criteria for a storm event as defined by the global setting and these have been included in the analyses.

After the model network has been developed and flows are inputted, the next step in the development process is to calibrate the model. This consists of changing characteristics of the model network and subcatchments to accurately portray what is happening in the actual wastewater system. The first step is dry weather calibration. This is the process of modifying the model network to reflect what is actually happening in the sewer system during a normal dry day. Following dry weather calibration, wet weather calibration is performed. This is the process of adjusting subcatchment parameters to reflect what is actually occurring in the sewer system during wet weather events.

The dry weather calibration begins by incorporating significant defects identified during the CCTV inspection that would affect wastewater flow. Sediment depths, blockages, and other flow restrictions are identified and then incorporated into the model. Based on the type of defect identified, Manning's coefficient "n" may be changed to reflect increased pipe surface roughness. "Observed vs. Predicted" plots are generated at the flow monitoring sites to see how the model compares to the flow meter data. Any sites that required modification to meet flow depth, volume of flow, and velocity were adjusted in the model to correspond to or at least approach the flow meter readings.

All of the meters in the Patapsco sewershed meet the established requirements in the BaSES Manual for dry weather calibration regarding flow volume and timing of peaks. The shape and timing of the predicted hydrographs were compared to the observed hydrographs and major discrepancies were corrected by adjusting the diurnal curves. Depths and velocities were also compared and the roughness factors and sediment depths were adjusted in the model to approximate the observed flow values. The model simulations time period for the dry weather calibration was run for one week and the volumes of the predicted vs. observed flow are totaled by InfoWorks for that time period. The curves developed by the model were visually inspected to ensure that the peak flow rates were in general agreement with the observed flow rates. All of the meters met the requirements of the BaSES manual for flow volume, with several predicted hydrographs almost identically matching the peak flows and volumes observed at the meter sites.

Following completion of the dry weather calibration, wet weather calibration was initiated. After reviewing the results of the global storm events, different criteria were adjusted to have the model more accurately predict the flow meter responses. When looking at the observed and predicted RDII volumes, there are notable differences between “summer” (Day Light Savings Time) and “winter” (Eastern Standard Time) storms. Summer storms are typically of shorter duration and higher intensity than winter events. In addition, the ground is usually dryer and the water table is usually lower in summer compared to winter. This means more precipitation is stored in the ground resulting in less runoff from a given storm event in summer compared to winter storms. Conversely, with the ground wetter and the water table higher, more runoff occurs from the same rain event in winter than in summer. Because of this, more RDII, the wet weather component of wastewater, usually enters the sewers during winter storm events as compared to summer. Because of these observations, it is difficult to calibrate the model to accurately predict both winter and summer storm events. One option would be to calibrate just on the higher winter storms, producing larger and thus more conservative RDII volumes; however, this approach would overstate the volumes of RDII associated with summer storms. To overcome these concerns, all storms were used to develop what is essentially a “median” R value to be used in the model. In addition, subcatchment widths were either increased or decreased as needed to increase or decrease predicted wet weather flow rates. In one basin, PA12, an additional runoff surface was created to simulate increased RDII. Using these approaches, the calibration guidelines were generally met.

To assess the validity of the model, a series of statistical comparison plots were produced as outlined in BaSES. A regression line with an R^2-value close to 1.00 indicates a good fit between the modeled and observed peak flows and volumes, while an intercept of the regression line close to zero indicates that the modeled event volumes and peak flow rates are not biased (i.e., consistently over-predicting or under-predicting) with respect to the monitored volumes and peak flow rates. When using the actual “R” values based upon the flow meter data, regression lines tend to vary from the ideal parameters. As noted above, the summer storms have less RDII per rainfall depth than in winter storms. This skews the regression line away from the ideal. The design storms to be used in the capacity analysis are more typical of the summer type storms (i.e., high intensity, low duration). With the Patapsco model calibrated to all storms, this provides a somewhat conservative capacity estimate, while not over-designing alternatives. To conclude the wet weather calibration, the observed vs. predicted graphs generated by InfoWorks were reviewed to assess the shape and timing of the hydrographs, and adjusted if necessary to have predicted results approach observed results.

The hydraulic model of the Patapsco Sewershed has been built in accordance with the Consent Decree and as outlined in the BaSES manual. The model network was built from field verified GIS information and the flow inputs are based on 17 individual flow meters that were installed for over one year. The dry weather calibration was completed without having to utilize any unrealistic conditions or assumptions. The wet weather calibration utilized an “R” value derived from the plots of Q vs. i for all storm events. When reviewing all global storms as a whole and balancing the differences between observed and predicted flows, the model behaves in a realistic fashion. Based on these facts and the provided supporting material, the Patapsco hydraulic model has been deemed “calibrated” and the baseline and future flows capacity assessments can begin.

1.0 PROJECT DESCRIPTION

1.1 Project Location

The Patapsco Sewershed encompasses approximately 5,000 acres within the City of Baltimore, as depicted on Figure 1. Wastewater from Anne Arundel County flows into the City's Patapsco sewershed at four locations, three of which are metered, as well as an unmetered 8-inch connection at Church Street near Muriel Avenue. The Patapsco sewershed includes the residential neighborhoods of Cherry Hill, Brooklyn, Curtis Bay and Brooklyn Manor, as well as the industrial areas of Fairfield and Wagner's Point. The industrial areas include heavy industries such as oil and chemical refineries, petroleum and chemical storage tanks, warehousing and manufacturing facilities. In addition, the CSX Curtis Bay Yard and CSX Coal and Ore piers add to the significant industrial and rail activity in the sewershed. Although there is an extensive industrial presence in the area, there are also large tracts of residential areas. The sewershed population within the City is approximately 21,000. Although most of the waterfront properties are now in industrial or commercial use, redevelopment along waterfront areas could bring increased population and wastewater flows compared to the current land uses.

The Patapsco Sewershed within the City of Baltimore includes over 268,285 feet of sanitary sewers that ultimately drain to the Patapsco Wastewater Treatment Plant. This total includes pipe sizes ranging from 4-inch to 64-inch. Of that total, 12,975 feet of sewers lie in sub-sewershed PA-13, which drains to the Westport Pumping Station, which then discharges into the Southwest Diversion (see Figure 1). Although the Southwest Diversion traverses the entire length of the Patapsco Sewershed, it does not receive any flow from the Patapsco Sewershed, with the exception of sub-sewershed PA-13. The sewers and manholes in sub-sewershed PA-13 are not part of the Patapsco Sewershed evaluation, but are included in the City's Gywnn's Falls sewershed study, Project # 1032. Of the approximately 256,000 feet of sanitary sewers in the Patapsco Sewershed evaluation, there are over 80,000 feet of sewers 10-inches and larger included in the hydraulic model. In addition, there are approximately 3500 feet of critical 8-inch sewers included in the model network.

1.2 Sub-Sewersheds

The Patapsco Sewershed consists of fourteen sub-sewersheds, PA01 through PA13, plus PA05A. The boundaries for each of the sub-sewersheds are depicted in Figure 2. As noted above, PA-13 drains to the Westport Pumping Station which then discharges into the Southwest Diversion. Other than the flow from PA-13, the Southwest Diversion contains flow transferred from the Gywnn's Falls sewershed in southwestern Baltimore City, as well as flow from Baltimore and Howard Counties, and is not part of the Patapsco Sewershed Evaluation. Thirteen sub-sewershed areas are included in this evaluation of the Patapsco sewershed, specifically PA01 through PA12, plus PA05A.

1.3 Consent Decree Requirements

A Consent Decree was agreed upon between the City of Baltimore, the United States Environmental Protection Agency and the Maryland Department of the Environment in April, 2002. One of the elements required by this Consent Decree is the development of a hydraulic model of the entire sewer system in the City, including the Patapsco sewershed. The requirements for hydraulic modeling are detailed in Paragraph 12 of the Consent Decree and are discussed more fully in Section 3.1 of this report. The purpose of the hydraulic model is to evaluate the capacity of the existing sewer system and the impact of proposed improvements and future development on the sewerage system. The Consent Decree also requires that an evaluation of infiltration and inflow (I/I) into the Patapsco sewershed be conducted. A separate report addressing I/I, dated September, 2009 has been submitted.

1.4 Purpose and Scope

This report details the development and calibration of the hydraulic model of the Patapsco Sewershed within the City of Baltimore. The calibration includes both dry weather and wet weather calibration.

2.0 FLOW MONITORING

2.1 Flow Monitoring Program

To fully understand the dynamics of the wastewater collection system, the City completed a detailed City-wide monitoring program. The program consisted of flow meters within the City's collection system and rain gauges spread throughout the City and Baltimore County. The flow monitors measured depth and velocity, from which flow was calculated at five minute intervals. The monitoring program consisted of over 350 flow monitors City-wide, with 17 of the meters located within the Patapsco sewershed, from May 9, 2006 to May 18, 2007. Some monitors deemed long term meters have stayed in place. See Table 1 for a list of meters, their sub-basin or service area, and purpose, and Figure 2 for the location of the meters and rain gauges. Figure 3 depicts a schematic of the flow monitoring plan. In addition to the flow monitors, 20 rain gauges were installed City-wide with some gauges installed outside of the City limits. All 20 rain gauges were utilized in conjunction with a Doppler radar rainfall analysis to generate rainfall data.

TABLE 1 - LIST OF FLOW METERS

SITE_ID	MANHOLE_ID	SITE_LOCATION	PURPOSE
BPA01 (LT)	S39E2_004MH	4116 Townsend Ave.	Model Calibration
BPA02 (LT)	S35Y1_026MH	59 Talbot St.	Model Calibration
BPA03 (LT)	S45K2_011MH	1525 Benhill Ave	Model Calibration
PA01 (LT)	S55A2_003MH	300 N. Northbridge on Asiatic Ave.	I&I Analysis/Model Calibration
PA03	S47K2_029MH	5014 Curtis Ave at Benhill Ave.	I&I Analysis/Model Calibration
PA04	S47G2_011MH	4512 Curtis Ave.	I&I Analysis/Model Calibration
PA05 (LT)	S49A2_002MH	1750 Patapsco Ave	I&I Analysis/Model Calibration
PA05A	S41U1_007MH	751 Frankfurst Ave.	Model Calibration
PA06	S43W1_015MH	3400 9th St.	I&I Analysis/Model Calibration
PA07	S41Y1_027MH	700 Pontiac Ave.	I&I Analysis/Model Calibration
PA08	S39U1_017MH	5th Street at Baltic Ave.	I&I Analysis/Model Calibration
PA09 (LT)	S37U1_028MH	3500 Hanover St. at Baltic Ave.	I&I Analysis/Model Calibration
PA10 (LT)	S33Q1_008MH	3200 Cherryland Road	I&I Analysis/Model Calibration
PA11	S33Q1_006MH	700 Reedbird Ave.	I&I Analysis/Model Calibration

SITE_ID	MANHOLE_ID	SITE_LOCATION	PURPOSE
PA12	S29U1_004MH	600 W. Patapsco Ave	I&I Analysis/Model Calibration
PA13 (LT)	S27G1_020MH	2900 Waterview Ave	*
PSBRO	S337S1_012PS	Hanover St. at Frankfurst Ave.	Model Calibration
PSWES	S27G1_022PS	Waterview Ave. att Cherry Hill Rd.	*
TSPA01(LT)	PATAPSCO	Patapsco WWTP	**
TSPA02	-	Chesapeake Ave. and 6th Street	**
TSPA03 (LT)	S55C2_006MH	In Easement South of Northbridge Ave.	I&I Analysis/Model Calibration
	* Part of Gwynn's Falls (GF) Sewershed ** Trunk Sewer Meters on Southwest Diversion, Part of P9 GF SS		
	LT = long Term Meter that remained after the May, 2006 to May, 2007 assessment period		

2.2 Flow Monitoring and Rain Gauge Sites

The 17 flow monitoring sites within the Patapsco sewershed provided useful wastewater flow data. The majority of the sites were installed primarily for infiltration and inflow (I&I) evaluation, although these were also considered in the calibration of the model. Four of the monitoring sites were primarily utilized for the calibration of the hydraulic model. See Table 1 for a list of the meters and their primary purpose. Using the City's Geographical Information System (GIS) the metering sites for I&I evaluation were selected at a meter density of approximately one for every 25,000 linear feet of sewer pipe. The monitors used are area-velocity meters designed to calculate flow based on measured depths and velocities in sanitary sewer pipes under free-flow and surcharged conditions. The primary depth sensor is ultrasonic with a resolution to the nearest 0.01 foot. The meters have level measurement redundancy, in the form of a pressure sensor, with accuracy of +/- .25 percent of full scale. The project required that the primary velocity sensor use Doppler technology, capable of measuring flow velocities in the range between -5 to +15 feet per second. The sensors were securely attached to the pipe by means of metal bands or anchoring hardware designed specifically for that purpose.

To measure the rainfall, a network of 20 rain gauge stations with a minimum coverage of one (1) rain gauge station per ten (10) square miles was installed and data was compiled by Doppler radar to generate a minimum resolution of one (1) pixel per one (1) square kilometer. To measure the contribution from rainfall occurring in portions of the Collection System outside Baltimore City, additional rain gauges were installed outside the City limits. The rain gauge equipment was calibrated prior to installation. The equipment consisted of a data logger able to accept data from an industry standard rain tipping bucket. The equipment was able to measure 0.01 inches (or 1mm) per tip of bucket. The tipping bucket consisted of a corrosion resistant funnel collector with tipping bucket assembly.

2.3 CALAMAR Rain Data

In accordance with the requirements of the Consent Decree, the City, through a Contractor, performed Doppler Radar Rainfall Analysis in conjunction with rain gauges at a resolution of 1 gauge for every 10 square miles. The Contractor utilized the CALAMAR software platform to process each recorded rainfall event with an average total depth of greater than 0.5 inches of rain. CALAMAR is a tool used to study the hydrologic impacts of precipitation through a combination of radar images and a network of rain gauges installed over a geographic area. CALAMAR uses three databases: a radar image database, a rain gauge database and a geographical database. After collecting the rain gauge network data and the radar images, CALAMAR produces a model that provides geographically accurate, integrated rainfall intensity data for any pre-defined area. The Baltimore City geographical area was divided into 1 square kilometer pixels, and for every significant rain event, Doppler Radar rainfall images were generated for every pixel within the Back River and Patapsco WWTP service areas. The output from the CALAMAR data is a file with a .RED extension that is directly imported into InfoWorks. A total of 26 global storms occurred during the flow monitoring period. The dates of those storm events are in Table 2 below.

TABLE 2
STORMS USED FOR WET-WEATHER CALIBRATION

Date	Depth (in)	Peak Intensity (in/hr)	Duration (hr)
May 11, 2006	1.678	2.193	8
June 1, 2006	0.179	0.524	2
June 2, 2006	1.1732	3.031	4
June 19, 2006	0.554	3.504	5
June 25, 2006	5.238	4.484	39
July 5, 2006	2.311	1.988	12
July 22, 2006	1.276	4.717	9
August 7, 2006	0.78	2.803	2
September 1, 2006	1.935	0.343	26
September 5, 2006	1.629	1.417	8
September 14, 2006	1.638	0.547	38
September 28, 2006	1.015	2.319	7
October 5, 2006	1.728	0.386	44
October 17, 2006	1.136	0.378	9
October 27, 2006	1.634	0.488	30
November 7, 2006	1.472	0.594	15
November 16, 2006	2.244	2.161	9
November 22, 2006	0.551	0.161	11
December 22, 2006	0.938	0.232	15
January 1, 2007	0.843	0.547	12
January 7, 2007	0.833	0.287	17
March 1, 2007	0.922	0.5	15
March 15, 2007	1.996	0.74	26
April 4, 2007	0.302	0.858	5

TABLE 2 (CONTINUED) STORMS USED FOR WET-WEATHER CALIBRATION			
Date	Depth (in)	Peak Intensity (in/hr)	Duration (hr)
April 11, 2007	0.622	0.417	17
April 14, 2007	2.664	0.961	31

It should be noted that some of the longer multi-day rain events were separated into separate storms events in the provided CALAMAR data to facilitate the file size limitations of InfoWorks, resulting in more CALAMAR rain events files than actual rain events.

2.4 Sliicer.com Analysis

All 17 flow meters installed in the Patapsco Basin were analyzed using the Sliicer.com software, as required. The outputs of the analysis were: weekday and weekend diurnal peaking factors; wastewater production rates; base infiltration; capture coefficients; and initial loss values. The peaking factors and flow rates were directly inputted into the hydraulic model. The capture coefficients and initial loss values were used as starting points to begin the wet weather calibration and were modified as required to complete the calibration process.

The Sliicer.com analysis began with setting the global parameters as required by the City. Next, the dry day traces for each meter were edited to remove any outliers that may have passed through the filtering requirements (±15 percent of average dry day, no rain within 1, 3, or 5 days depending on the volume). The diurnal curves were then exported to Excel to develop peaking factors. The base infiltration was subtracted from the exported flow volumes, with the resulting number divided by the average wastewater production to obtain the hourly peaking factors. To complete the storm analysis in Sliicer.com, all of the global storms were reviewed. The precompensation amounts were modified as necessary and the outliers and storm events that occurred when the meter may have been out of service were removed. The slope (S) of the regression line on the Q vs. I plot was used in the equation:

R = (S in/mgd*38.85mgd-acre/in)/Area in acres

to compute the capture coefficient (R). The initial loss value was obtained from where the best fit line crossed the X axis or was set to zero if the line had to be forced through the origin. See Attachment 3 (PDF on attached CD) for RDII versus rainfall depth for each storm event along with the associated regression line fit to the data set.

A total of 21 flow monitors were installed in the Patapsco basin, as noted in Table 1 above. Of these 21 meters, 13 are at the low points of each of the sub-sewershed areas. One is in sub-sewershed PA-13, which, as previously explained, flows to the Westport Pumping Station and is not a part of the Patapsco collection system evaluation, and another is the flow meter at the Westport pumping station, which is also not in the scope of this evaluation. Among the other six meters, three measure flow coming into the Patapsco system from Anne Arundel County, two are on the Southwest Diversion, which does not contain wastewater from the Patapsco sewershed, and one measures the discharge from the Brooklyn Pumping

Station. Of the 21 meters physically within the Patapsco sewershed, 17 measure flow that is included in the scope of the Patapsco sewershed study. Some meters deemed long term meters have stayed in place, as noted in Table 1.

Based on the specific geometry of the wastewater system in the Patapsco sewershed (See Figures 2 and 3), nearly all wastewater flow in the basin goes through trunk sewer flow monitor TSPA03. TSPA03 is the only trunk sewer flow monitor in the Patapsco Low Level system. TSPA01 and TSPA02 are on the Southwest Diversion, a large diameter pressure sewer that discharges directly into the Patapsco Wastewater Treatment Plant. The evaluation of the Southwest Diversion is being performed in the Gywnn's Falls Sewershed Study, Project #1032. The sum of the flows measured in flow monitors TSPA03 and PA01 equals the wastewater generated in the Patapsco Low Level System as it enters the Patapsco Wastewater Treatment Plant's Pump and Blower (P and B) Building.

In addition, the Brooklyn Wastewater Pumping Station in the western side of the sewershed receives flow from BPA02, PA09, PA10, PA11 and PA12, and its discharge is measured by a venturi meter, which is PSBRO. This station contains two 3600 gallons per minute (gpm) pumps controlled by variable frequency drives and one constant speed 5700 gpm pump that acts as a standby. Flow Monitor PA05A includes the flow from PSBRO and PA08. Flow Monitor PA05 receives flow from upstream sewersheds and flow monitors PA06, PA07, BPA01, PA05A, PA08, PSBRO, PA09, BPA02, PA10, PA11 and PA12, and in essence serves as a trunk sewer flow monitor, although not labeled as such.

Although the primary purpose of most of the flow monitors was to evaluate infiltration and inflow potential, these meters also provided valuable flow information that was utilized in the calibration of the model.

3.0 MODEL DEVELOPMENT

3.1 General

As stated in Paragraph 12 of the Consent Decree, a model is required to be developed for each sewershed within the City. The model must be capable of evaluating the impact of I/I rehabilitation projects, proposed system modifications, upgrades and expansions on the transmission capacity and performance of the Collection System. The model is required to be capable of predicting:

1. The volume and rate of wastewater flow in force mains and major gravity lines
2. Hydraulic pressure or hydraulic grade line of wastewater at any point in force mains and the major gravity lines
3. Flow capacity of each of the pumping stations in the collection system
4. Flow capacity of each pumping station with its back-up pump out of service
5. Peak flows for each pumping station during storm events of a magnitude of up to 20 years
6. Likelihood and location of overflows under high flow conditions, including pumping station service areas where the pumping station's back-up pump is out-of-service, considering available wet well capacity, off-line storage capacity, and normal in-line storage capacity.

The model must also be:

1. Configured based on representative, accurate, and verified system attribute data (e.g., pipe sizes and invert elevations, manhole rim elevations, etc.)
2. Calibrated using spatially and temporally representative rainfall data and flow data obtained during the rainfall and flow monitoring period
3. Verified using spatially and temporally representative rainfall data and flow data that are independent of the data used to calibrate the model.

The sewershed consultants shall certify that:

1. The model includes all elements listed above in this section.
2. The model has been calibrated, including the performance of sensitivity analyses, and verified using actual flow data from metering locations in the sewershed.

3.2 Horizontal and Vertical Datum

The horizontal plane used for the hydraulic modeling is the Maryland State Plane Coordinate System (NAD83). The vertical datum used is NAVD88.

3.3 Modeling Software

3.3.1 InfoWorks CS

The modeling software selected for the City of Baltimore Collection System Evaluation and Sewershed Plan is InfoWorks CS, by Wallingford Software, Ltd. An evaluation team for the City selected this modeling software among others available as the best suited for the City of Baltimore system. As of the date of this report, the most recent version is InfoWorks CS 10.0.3.

3.3.2 Information Required

In order to run the hydraulic model for the Patapsco sewershed, data to describe the sewer system is required. The data required is for pipes, manholes and other junctions, control structures, pumping stations, and other features. Table 3 at the end of this section lists all the data included in the Patapsco hydraulic model.

3.4 Network Development

As stated in the Consent Decree, the modeled network shall include all force mains, major gravity lines, and pumping stations and their respective related appurtenances. Major gravity lines are defined in the Consent Decree as:

- All gravity lines ten inches in diameter or larger;
- All eight-inch lines that convey or are necessary to accurately represent flow attributable to a service area in each of the Collection System's sewershed service areas;
- All gravity lines that convey wastewater from one pumping station service area to another pumping station service area; and
- All gravity lines that have caused or contributed, or that the City knows are likely to cause or contribute, to capacity-related overflows (utilizing the City's Water In Cellar (WIC) database).

The model also includes all manholes, junctions, and structures along model sewer lines and all control structures (e.g. weirs and pumping stations) existing in the system.

3.4.1 GIS Development

The City's wastewater geodatabase was used as the primary source of information for creating and populating the pipes and nodes network of the InfoWorks hydraulic model. One of the first tasks was to establish the GIS features that would be part of the hydraulic model. Pipes currently attributed in the City's geodatabase were selected using the 'select by attribute' command in ArcMap, selecting pipes where the field WIDTH is greater than or equal to 10 inches. The GIS Analyst exported the selected records into a shapefile. The shapefile was reviewed by the Modeling Engineer to check for pipes that were incorrectly attributed in the City's geodatabase. Abandoned lines and the Southwest Diversion, which is not in the scope of the Patapsco Sewershed Study and Evaluation, were removed. Missing pipes were copied from the City's geodatabase and pasted into the shapefile. The GIS Analyst then changed the incorrect pipe size attribute in both the shapefile and geodatabase under direction from the modeling engineer. The Engineer then checked the model network for connectivity, and made corrections where needed. After further review by the Engineer, approximately 3500 feet of 8-inch sewers that provide continuity between 10-inch sections or between subcatchments, were added to the model network.

A shapefile was created for point features from the following geodatabase layers: WW_ManholeJunction; WW_Bend; WW_SewerEnd; WW_SewerInter; WW_Lamphole; WW_MeterStn; WW_PumpStn; WW_TreatmentPlant; and WW_Valve. The GIS Analyst performed a 'select by location' action where each feature class is intersected with the existing sewerline shapefile. This produces a selection of points that are located at the ends of each sewer segment. These selected points are exported by the GIS Analyst into a separate shapefile, and those were combined into one point file for ease of use. The ID field was maintained for further reference and editing purposes.

WR&A utilized manhole inspection and CCTV information from project field survey efforts, along with City engineering record documents from the AIRS database, to make editing changes and enhancements to the City's wastewater GIS and the model network. To maintain the connectivity of the hydraulic model sewers within the GIS, the Engineer and GIS Analyst periodically performed a visual review of the modeled sewers.

3.4.2 Exporting the GIS Data to InfoWorks

The GIS data for the hydraulic model was exported from the GIS into a shapefile. This shapefile was then imported directly into InfoWorks software. The GIS Analyst followed these procedures in preparing the GIS for export to the hydraulic model:

1. Select all hydraulic model features.
2. Open the sewer feature attribute table to review the population of all key attributes (WIDTH, HEIGHT, SHAPE_CODE, IN_ELEV_SP and OUT_ELEV_SP). Any key attribute data that was missing was researched and populated in the model.
3. Export the selected hydraulic model features to a shapefile.

3.4.3 Manhole Inspection Data

Manhole inspections have been completed for the majority of the manholes in the Patapsco sewershed. Data collected from the manhole inspections include: the number, size and clock location of the pipes entering and exiting the manhole (outlet pipe in plan view is at 12 o'clock); the depth from the manhole rim to the invert of the manhole; the depth of sediment, sludge or other debris in the connecting pipes; the general condition of the manholes; and other attributes and condition assessment data. Information from the manhole inspections were used to supplement, verify or correct data brought into the model network from GIS and record drawings.

3.4.4 Record Drawings

Record drawings for the Patapsco sewershed were obtained from the City. These records included all the available drawings listed in the AIRS database. Information from these drawings has been transferred into the GIS for the Patapsco sewershed. Data obtained from the record drawings include: pipe sizes, shapes and materials; invert and ground elevations; manhole shapes, sizes and locations; and weir locations and sizes. Pumping station data including number of pumps, their capacity, and wetwell elevation controls were obtained from record drawings and field visits to the stations.

3.4.5 Surveys

On manholes on modeled sewer lines (10-inch and greater plus critical 8-inch lines), Real Time Kinematic (RTK) surveys were performed to record the x, y and z coordinates (northing, easting, and elevation) of the manhole rims. To populate the inverts of the modeled sewers, the distance from the surveyed rim elevation and the invert was measured and recorded. To date, approximately 450 survey-grade GPS locations on model manholes have been quality reviewed and imported into the model and GIS. For some manholes, elevations were established through a document review process using AIRS documents and additional record documents obtained at the City. A small number of invert elevations that were not available from GIS, surveys or record document research were estimated using available information and sound engineering judgment.

3.4.6 Data Flagging and User Text Fields

All of the information imported into InfoWorks was flagged to correspond to the capture method utilized and the type and source of data. Information that had to be modified, edited or updated for modeling purposes had their flags similarly updated to indicate the data source utilized in making the change. Some flags are provided in InfoWorks. Other flags utilized came with the Macro Model that was developed by the City, and the modeler of the Patapsco system added other flags. Notes explaining why changes were required were added to the Notes and User Text columns in InfoWorks. In addition, other columns in the InfoWorks Grid view and User Text fields were populated to assist in model development, to maintain relationships to GIS, and to determine the original data sources for the model information. Table 4 below shows the various data flags, their sources and codes, and a description of the data source.

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TABLE 4
PATAPSCO MODEL INFOWORKS DATA FLAGS

InfoWorks Flag	Flag Description	Origin	Notes
#A	Asset Data	InfoWorks	
#D	System Default	InfoWorks	
#G	Data from GeoPlan	InfoWorks	

TABLE 4 (CONTINUED) PATAPSCO MODEL INFOWORKS DATA FLAGS			
InfoWorks Flag	**Flag Description**	**Origin**	**Notes**
#I	Model Import	InfoWorks	
#V	CSV Import	InfoWorks	
AD	Assigned Values by Modeler	MacroModel	Further subdivided below
AS	Inferred or Assumed	MacroModel	Engineering Judgement
GD	GeoDatabase	MacroModel	
GI	Data Import from GIS	MacroModel	
OP	Data from Operations	MacroModel	Pump Curves, Wetwell Levels
RI	Record Information	MacroModel	As-Builts, Design Plans
WA	Wastewater Analyzer Office Model	MacroModel	
CC	CCTV/Manhole Inspection Data	Modeler	Field Inspection Data
PL	500 Scale Plat Maps	Modeler	Part of Record Information
SG	Survey – GPS Grade	Modeler	X, Y,Z of Manhole Rims
ST	Survey – Traditional	Modeler	

3.4.7 QA/QC Procedures

Before any simulations can be performed, InfoWorks requires that the model network be validated. Model validation consists of the correction of all system and network errors and warnings produced by InfoWorks such as lack of connectivity between nodes, incorrect length of sewer between nodes, inconsistent invert elevations (i.e., downstream inverts higher than upstream inverts), subcatchments that don't drain to a node, and reverse slopes. In addition, InfoWorks produces long view profiles that were reviewed to verify vertical correctness, appropriate ground elevations, and consistent invert elevations. Any discrepancies found were compared to field survey data, CCTV and manhole inspection records, and record drawing information, and the appropriate corrections were made.

In order to further refine the validation process, an "Engineering Validation" was performed. To accomplish this, the default validation settings provided in InfoWorks were modified and supplemented to provide additional QA/QC checks. In this process, the modeler adjusts the range of values against which the data is checked, assigns priority levels to classify the severity of the errors, and enables or disables validation rules. By modifying the default validation settings, the model can more accurately match the actual conditions in the Patapsco Sewershed, resulting in fewer warnings from InfoWorks that needed to be investigated.

3.5 Model Basin Development

3.5.1 General

The InfoWorks CS model for the Patapsco sewershed attempts to simulate the hydrologic characteristics of the sewershed. To do this, the model utilizes the SWMM surface runoff routine within InfoWorks. As this is surface runoff, and there are no combined sewers in the Patapsco sewershed, the wet weather flow input to the sanitary sewer system needs to be developed. The SWMM surface runoff routine is used as a surrogate rainfall-dependent infiltration and inflow (RDII) simulator. The parameters used in the surface runoff routines are adjusted to match the observed inflow; however, those parameters do not have actual physical significance in the sanitary sewer system. Hence, for wet weather flow simulation in separate sanitary sewers, the surface runoff routine of SWMM is being applied to empirically develop RDII flows in the InfoWorks model. This procedure has the advantage of allowing inflow simulation as a function of rainfall depth and spatial distribution, within the framework of the model rather than outside of it.

3.5.2 Subcatchment Areas

The Patapsco sewershed has been divided into sub-sewersheds based on the flow monitoring basins. These basins have been incorporated into the InfoWorks model as subcatchments. In addition, each of the flow monitoring basins has been further divided into multiple subcatchments (See Figure 4). The subcatchments were developed using the following guidelines as stipulated in the BaSES Manual:

- Subcatchment areas should be roughly 10-40 acres in size, with an average of approximately 20 acres. Exceptions to these guidelines occur at the upstream reaches of SSAs and at points in the basins where there is little or no flow contribution. These exceptions result in larger subcatchment areas.

- Subcatchment boundaries should generally be drawn at hydraulic control points such as:
  - Flow diversion chambers
  - Pumping stations
  - Significant tributary junctions
  - Flow Monitor locations

- Large parcels of land in the subcatchments, such as parks, rail yards, industrial sites, and highways that contribute little or no flow to the collection system, are not included as contributing areas in the SWMM runoff routine in InfoWorks

For each subcatchment, a load point node is identified for the assignment of dry and wet weather flows into the hydraulic model network. Model load points are chosen to best represent flows entering the system. Dry pipes that do not receive flow from an upstream load point are not included in the model.

The subcatchment ID in InfoWorks closely follows the corresponding flow monitoring basin name. In instances where the subcatchment and the flow monitoring basin are identical, the subcatchment ID matches the basin name. Where the basin has been subdivided into multiple subcatchments, a one character alpha suffix, beginning upstream with “A” and proceeding downstream, has been added to the flow monitoring basin name.

3.6 Dry-Weather Flow Development

3.6.1 General

There are several sources of data used in the development of dry weather flows in the InfoWorks model. These sources include:

- Rainfall and flow monitoring data that is analyzed using the Sliicer.com software
- Recorded flow data at the Brooklyn Pumping Station and the Low Level Pumping Station at the Patapsco WWTP
- The City’s database of water consumption records for each SSA, and the listing of the top one hundred water users in the sewershed as compiled by the City
- Population estimates for each sewershed service area (SSA) obtained through GIS intersection with the U.S. Census Block data
- GIS estimates of tributary collection system to each flow monitor, measured in inch-diameter-miles
- GIS estimates of the tributary sewershed area to each flow monitor

3.6.2 Flow Analysis

The flow analyses conducted using the Sliicer.com software provide estimates of the components of the dry weather flow, specifically, the average base sanitary flow (BSF) and the groundwater infiltration (GWI) rate, at each flow monitoring site. It is important to note that these flow components are not measured directly, but are estimated and calculated based on certain assumptions. Seasonally, minimum wastewater flows occur during the summer, and minimum daily flows occur during the night, between the hours of 2 and 4 AM. During these hours, it is assumed that most of the sewer flow is due to GWI. GWI is often assumed to comprise 88 to 90 percent of these nighttime flows. Sliicer.com has several methodologies for estimating BSF and GWI. For the purposes of developing flows for the model, the Stevens/Schutzbach equation was used for calculating GWI, as shown below:

GWI = (0.4*Min Daily Flow) / (1-0.6(Min Daily Flow/Average Daily Flow) ^Average Daily Flow^0.7).

The BSF is then estimated as the dry weather flow rate less the GWI estimate. In situations where this subtraction yields negative GWI, the GWI is estimated as a percentage of the BSF.

The BSF values were validated prior to input to the InfoWorks model. Validation of the

BSF for residential areas was performed by dividing BSF by the population of the sewershed service area to determine the per capita wastewater generation rate. These results were then compared to industry standards and engineering textbook values for per capita wastewater production for residential areas. Typical per capita wastewater generation rates range from 50 to 350 gallons per capita per day, depending on a wide range of variables, including housing type, age of house and plumbing, amount of land surrounding the house, family size, employment rate, etc. Non-typical values required further investigation or explanation.

For sewershed service areas which include industrial and commercial water users, the water consumption records, including the Top 100 City Water Users database, were reviewed to determine average daily BSFs from these facilities and to validate the corresponding BSFs obtained through the Sliicer.com analyses. In heavy industrial areas, such as those in sub-sewersheds PA05, PA05A and PA02, there is the possibility of consumptive water uses, such as cooling/evaporation and product incorporation, which would reduce the amount of water use that is returned to the sanitary sewer system as BSF. Conversely, there is the possibility of these industries using ground water in their processes, which is then returned to the sanitary sewer, resulting in wastewater flow higher than water use, although this has not been confirmed. For some industrial areas, industrial wastewater production was added as a “trade flow” in InfoWorks to assist in flow balancing and create a realistic flow pattern to match the flow monitors.

Validation of the GWI estimates is not as straightforward as the BSF validations. GWI can vary greatly based on the condition of the sewer and the elevation of the groundwater table. To determine the relative amount of GWI, an estimate of the amount of sewers tributary to the flow monitor is determined, in units of inch diameter-miles, and the GWI is then normalized by dividing GWI by the inch diameter-miles estimate. Textbook values can be used to determine if the normalized GWI estimate is indicative of a tight or leaky sewer system. According to industry standards, the amount of infiltration that can enter a sanitary system has a range from 100 to 10,000 gallons per day per inch-mile of sewer, depending on a large number of variables such as pipe condition and material, surrounding soil types, water table elevation, etc.

The Sliicer.com analyses yields average daily dry weather flow hydrographs for each sewershed service area for both weekdays and weekends, and by “season” (Daylight Savings and Eastern Standard Time). This data was then used to develop hourly diurnal peaking factors for weekdays and weekends. This was done by first subtracting the GWI from the hourly values of the dry weather flow hydrographs and then dividing by the average BSF.

In the InfoWorks model, a profile in the wastewater group has been created for each sewershed service area. The wastewater profile contains weekday and weekend hourly diurnal peaking factors. In addition, a per capita wastewater generation rate is specified in the wastewater profile. This generation rate, multiplied by the subcatchment population, yields the average BSF.

GWI has been represented in the InfoWorks model as a “trade flow”. The GWI component for a given sewershed service area was distributed to the tributary subcatchments based on relative sewershed area. The GWI, like all trade flows, is represented as a constant inflow, therefore, the hourly and monthly peaking factors in the trade waste profile are set to one. By representing GWI as a trade flow, there is flexibility to vary GWI on a monthly or hourly basis, in order to account for the variation in GWI due to seasonality. Each subcatchment was assigned the appropriate trade flow profile.

3.7 Wet-Weather Flow Development

3.7.1 General

Analysis of the flow monitoring data also yields model input for the simulation of wet weather events. The wet weather flow component in sanitary sewers is referred to as rainfall-dependent infiltration and inflow (RDII).

3.7.2 SWMM Routine within InfoWorks CS

The approach proposed to simulate the wet weather flow component in sanitary sewers in areas served by separate storm sewers uses the SWMM RUNOFF routines in InfoWorks CS as a synthetic storm hydrograph generator. SWMM was originally intended to simulate urban runoff collection systems, specifically, stormwater drainage systems and combined sewer systems. The application of this model to separate sanitary sewer systems differs from the more conventional use of RUNOFF to simulate overland flow and related phenomena. In a sanitary system, the RDII is driven not by the impervious surface of the modeled catchment, but by a myriad of factors including:

- Age and condition of the sanitary sewer system
- Construction practices at the time of sewer installation
- Prevalence of direct (illicit) connections of stormwater to the sanitary system
- Operation and maintenance practices by the Owners of the system
- Antecedent moisture conditions (i.e., the saturation of the ground around the sewers prior to a wet weather event)
- Groundwater elevation

To simulate RDII in sanitary sewer systems, suitable input parameters are selected to yield flows that match the wet weather flows determined from flow meter measurements. These input parameters are therefore extensions of their normal use and definition in a stormwater application. The following is a description of the steps used to develop initial parameter estimates for the inflow model.

Simulating RDII using SWMM RUNOFF within InfoWorks requires the specification of catchment characteristics that result in RDII values that approximate the wet weather component determined from the flow monitoring program. These catchment characteristics do not have physical significance in the sewershed. Rather, they allow simulation of RDII using runoff calculation formulations. The parameters to be specified are:

- Area: The total area of each subcatchment (in acres). See the discussion of area in the development of the capture coefficient, R, below.

- R-Value (Percent Capture): The SWMM RUNOFF routines simulate wet weather from a modeled basin via impervious and pervious runoff. Impervious runoff represents that portion of flow generated from paved surfaces, such as parking lots, roads, sidewalks and driveways and from other impervious surfaces such as building roofs. For sanitary sewer systems, the percent impervious is analogous to a percent capture or more appropriately an RDII "R-Value". The R-Value represents the fraction of the rainfall that enters the sanitary sewer system. Rainfall and flow metering data in Sliicer.com provide an estimate of the R-Value, as noted below.

The infiltration factors for pervious areas are adjusted such that there is no runoff (RDII) from pervious areas. The volume of RDII is proportional to the rainfall depth, using the following equation:

$$V = CA*(D-DS)$$

Where:

V = RDII volume, cubic feet
C = R-Value (equivalent to percent capture)
A = catchment area, square feet
D = rainfall depth, feet
DS = Depression storage, feet

The value of C is determined by analysis of flow measurement data. After separating the rainfall-induced flow for a number of storms, RDII volumes are calculated and plotted versus rainfall depth (Q vs. i). C, the percent capture, is proportional to the slope of the regression line between RDII (Q) and rainfall depth (i).

The area utilized in this equation is not always the gross area of a subcatchment. Rather, in certain subcatchments, the area is reduced, or "clipped" to include only those areas that have the potential to contribute RDII to the sewer system. Several of the sub-sewershed areas border bodies of water such as the Patapsco River, Curtis Bay and Stonehouse Cove. Those portions of sub-sewersheds that drain directly into these water bodies and do no not include sanitary sewers are removed from the area contributing flow in a subcatchment. Also, portions of the CSX Curtis Bay Freight Yard in which there are no sanitary sewers, were similarly excluded from the area calculation.

- Depression storage: Depression storage represents the volume of rainfall that needs to occur before the occurrence of runoff. For surface runoff, it represents the initial loss or "abstraction" caused by such phenomena as surface ponding, surface wetting, interception and evaporation. For determining RDII for modeling purposes, this parameter represents the depth of rainfall, in inches, required to initiate a response in the sewer system. In this application, depression storage has been estimated using the intercept of the RDII volume vs. rainfall (Q vs. i plot in Sliicer.com) regression line. Typical values for depression storage range from 0.1 to 0.5 inches, and can vary greatly for an area depending upon the antecedent moisture conditions.

- Width: Subcatchment width is a key calibration parameter, which can significantly alter the hydrograph shape (i.e., timing of the peak flow rates) without impacting the volume. Subcatchment width is directly proportional to peak flow rate. The subcatchment width is determined when the simulated time-to-peak and flow magnitude match the observed peak RDII flow during several storm events. This is done by simulating storm events using the model and adjusting the catchment width until the simulated peak matches the observed peak.

- Slope: For combined sewers and stormwater (surface runoff) models, this value represents the physical slope of the ground surface. As previously stated, when the surface flow routine of SWMM RUNOFF is used to simulate RDII flows, the parameters used are not physically pertinent to sanitary sewer systems; however, adjustment of these parameters can produce results in the model that simulate the effect of runoff on the wet weather component of wastewater. An average basin ground slope can be calculated using GIS. This value can be modified to adjust the modeled peak flows and volumes during model calibration, but it is not a particularly sensitive parameter.

- Overland Flow Routing Coefficients: Manning’s roughness coefficient can be adjusted to further fine tune the simulated hydrograph response to have it more closely resemble observed values. Experience has shown that a value for Manning’s roughness coefficient for a subcatchment in a separate sanitary sewer system ranges from 0.015 to 0.05.

3.7.3 Flow Analysis

The RDII volume versus rainfall depth plot (Q vs. i plot in Sliicer.com terminology) for each monitoring site has been developed using Sliicer.com software. In addition, Sliicer.com also develops the best-fit linear regression line to the data set and the corresponding equation for the regression line, as well as the R-Value. Twenty-nine storms have been considered in the analyses. These storms are listed in Table 5 below.

TABLE 5
STORMS USED FOR DEVELOPMENT OF R-VALUES

5/11/2006	6/25/2006	9/14/2006	10/27/2006	12/25/2006	3/23/2007
5/14/2006	7/5/2006	9/28/2006	11/7/2006	12/31/2006	4/4/2007
6/2/2006	7/22/2006	10/5/2006	11/16/2006	1/7/2007	4/11/2007
6/19/2006	9/1/2006	10/17/2006	11/22/2006	3/1/2007	4/14/2007
6/24/2006	9/5/2006	10/19/2006	12/22/2006	3/15/2007	

3.8 Boundary Conditions

To accurately reflect the hydraulics of the sewershed, boundary conditions need to be included within the model. There are four sources of flow from Anne Arundel County included in the model. Three Anne Arundel County sub-sewersheds flow into the Patapsco sewershed at flow monitors BPA01, BPA02 and BPA03. There is also an unmetered 8-inch connection from the County at Church Street near Muriel Avenue that flows into sub-sewershed PA03. Diurnal curves were developed for each of the three flow meter sites and their average flows inputted into the model. The boundary sewersheds provided with the macro model were the initial source of information for the boundary sewersheds in the micro model, although additional record information had to be utilized to fully develop the flows and contributory areas from the County. Capture coefficients or "R" values were first estimated through Sliicer.com and then fine tuned through the calibration effort.

Based on the specific configuration of the Patapsco sewershed, it discharges directly into the Patapsco Wastewater Treatment Plant (WWTP). There are two sources of influent flow to the WWTP. One is the Southwest Diversion, an 84-102-inch pressure sewer that delivers flow from outside the Patapsco drainage basin to the WWTP. The Southwest Diversion is not in the scope of the Patapsco Sewershed Study and Evaluation. The second influent to the WWTP is from the so-called Low Level System, which outfalls to the WWTP in a 48-64-inch tile and concrete box sewer. Trunk sewer flow monitor TSPA03 is on the box sewer just upstream of the headworks of the Patapsco WWTP. Downstream of TSPA03, PA01 joins the box sewer just outside of the Patapsco WWTP. Therefore, the total WWTP influent flow from the Low Level System is the sum of the flows measured at PA01 and TSPA03. The flow then enters the Pump and Blower (P and B) Building, where there are four 6000 gpm (8.64 mgd) raw wastewater pumps, one of which is in standby mode. The raw water pumps lift the wastewater from the Low level System into the primary clarifiers. The wetwell in the P and B Building has a high water level of -6.30, and a low water level of -11.00. Pre-set level controls turn pumps on and off at different elevations between those ranges. The water level in the influent channel to the primary settling tanks is at elevation 18.90. The flow from the pumps is measured in a 24-inch venturi tube before entering the primary clarifiers. All of the above parameters were utilized in the calibration of the model and for establishing the outfall boundary condition in the micro model. Figure 3 shows the Boundary Conditions for the Patapsco sewershed.

TABLE 3
DATA INCLUDED IN THE PATAPSCO SEWERSHED HYDRAULIC MODEL

Category	Information Included	Notes
Manhole/Nodes	Node ID	
	Node Type (Manhole, break, outfall, storage)	"Nodes" are included at every manhole, intersection of pipes, outfall, etc. Break nodes in force mains have been modeled as manholes.

TABLE 3 (Continued) DATA INCLUDED IN THE PATAPSCO SEWERSHED HYDRAULIC MODEL		
Manhole/Nodes	X	Northing coordinate
	Y	Easting coordinate
	Ground Level	Ground levels are included for each node. Ground levels have either been obtained from survey data or interpolated record information
	Flood Level	Assumed to be the same as ground level
	Chamber Floor Level	Estimated to be the same as the invert of the lowest connecting pipe.
	Chamber Plan Area	Computed within InfoWorks based on size of connecting pipes
	Chamber Roof Level	Assumed to be equal to the crown of the highest connecting pipe.
	Shaft Plan Area	Computed within InfoWorks based on size of connecting pipes
	Flood Type	Flood depth assumed equal to rim elevation.
	Locations where sanitary sewer cross-connects with the stormwater system	Based on field inspections
Pipes	Upstream Node ID	
	Downstream Node ID	
	Length	Estimated from node XYs, GIS or record drawings
	Shape ID	In cases where the pipe is not circular, information on the exact shape has been provided.
	Width	
	Height	If pipe is circular, the height equals the width.

TABLE 3 (Continued) DATA INCLUDED IN THE PATAPSCO SEWERSHED HYDRAULIC MODEL		
Pipes	Roughness Type	Manning's roughness coefficients have been used. Value is based on pipe material. In the absence of pipe material data, a standard value of 0.013 is used
	Bottom Roughness	
	Top Roughness	
Category	Information Included	Notes
	Upstream Invert Level	
	Downstream Invert Level	
	Pipe age/material/condition	Deterioration of the system in future conditions will be accounted for.
Weir	Upstream Node ID	
	Downstream Node ID	
	Crest Level	
	Width	
	Height	
	Length	For broad-crested weirs only
	Notch Height	For V-notch weirs.
	Notch Angle	
	Notch Width	
	Number of Notches	
	RTC Parameters	If a weir is "variable" and requires RTC, then RTC information has been provided.
Flume	Upstream Node ID	
	Downstream Node ID	
	Invert Level	
	Throat Width	
	Throat Length	
	Side Slope	
Pump	Upstream Node ID	
	Downstream Node ID	
	Switch On Level	
	Switch Off Level	
	Delay	A default number has been used.

TABLE 3 (Continued) DATA INCLUDED IN THE PATAPSCO SEWERSHED HYDRAULIC MODEL		
Pump	Discharge (FixPmp Information Included and VspPmp Only)	
	Head Discharge Curve	
	Wet Well	Wet wells have been modeled as a storage node.
	RTC Parameters	If a pump has variable speed controls, RTC information has been provided.
Screens	Upstream Node ID	
	Downstream Node ID	
	Crest	
	Width	
	Height	
	Angle	
	Bar Width	
	Bar Spacing	
Gates	Upstream Node ID	
	Downstream Node ID	
	Invert Level	
	Width	
	Opening	
	RTC Parameters	If a gate is "variable" and requires RTC, then RTC information has been provided.
Inflow Information	Delineation	
	Meter Data	
	Dye/Smoke Test Results	If applicable
	Building/Road/ Parking (Impervious)	
	Population/Water Use Data	
	Contour Information	
	Pipe Condition	

4.0 MODEL CALIBRATION

4.1 General

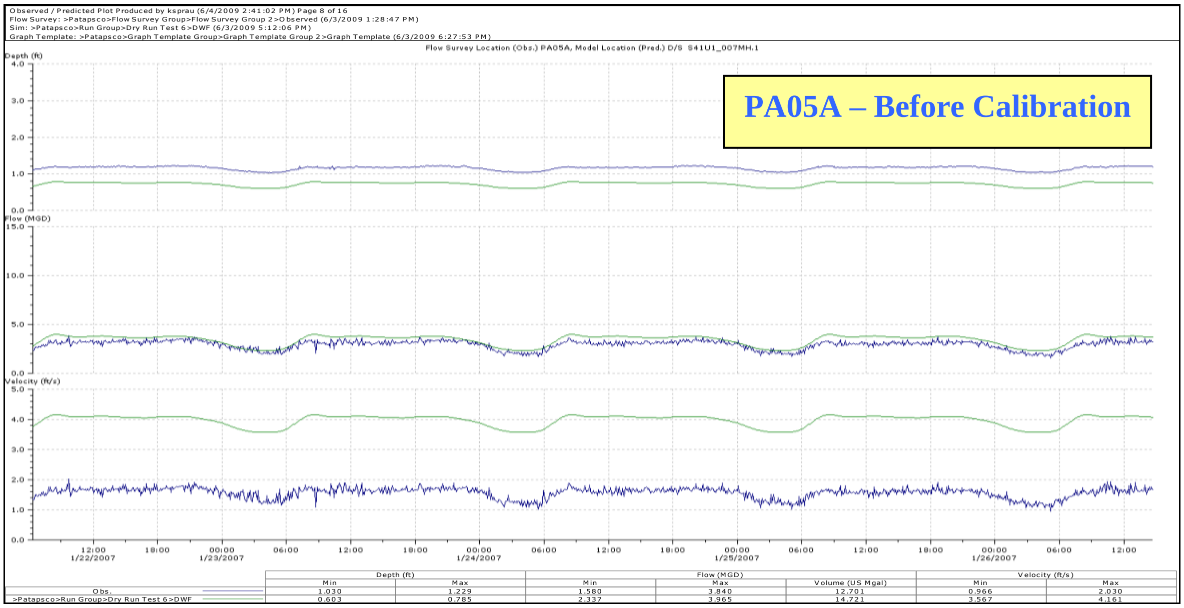
After the model network has been developed and the flows are inputted, the next step of the development process is calibrating the model. This consists of changing characteristics of the network and subcatchments to accurately portray what is happening in the actual wastewater system.

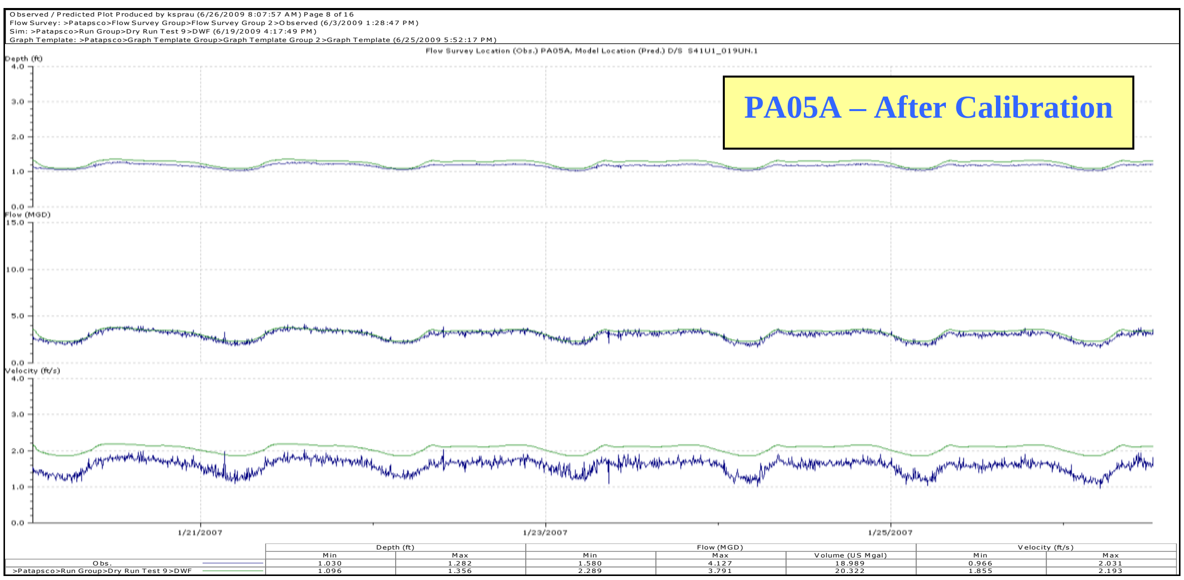
Model calibration consists of two steps. The first step is dry weather calibration. This is the process of modifying the model network to reflect conditions that approximate what is actually occurring in the sewer system during a normal dry day. Following dry weather calibration, the second step is wet weather calibration. This is the process of adjusting subcatchment parameters to produce wet weather flows (RDII) in the model that simulate or approach observed wet weather flows as recorded by the flow monitors during storm events.

4.2 Dry-Weather Calibration

Dry weather calibration begins by incorporating significant defects identified during field inspections into the model, such as sediment depths, blockages, and other flow restrictions. Based on the type of defect identified, Manning's "n" is changed to reflect increased pipe roughness. In addition, where CCTV or manhole inspections indicated sediment deposits, sediment depth was added to the pipe cross section in the model. Once the network has initially been populated, a simulation is run to get the first assessment of the behavior and accuracy of the model. Following the initial simulations, "Observed vs. Predicted" plots are generated at the flow monitoring sites to see how the model behaves compared to the measured flow meter data. Sites that do not show good congruence between observed and predicted parameters require modifications for the predicted values to approach the observed values for flow depth, flow rate, and velocity at the flow meters. For example, an early model run at flow meter PA05A is depicted in the following plot of observed vs. predicted depth, flow and velocity. The general shape of the predicted flow hydrograph matches well with the observed hydrograph (i.e., flow peaks and minimums are generally aligned). The volume of flow was 12.701 Mgal observed vs. 14.721 Mgal predicted, a difference of +15.9 %, and the peak flow observed was 3.840 mgd vs. 3.965 mgd predicted, or a difference of +3.3 %. Both of these parameters are within the calibration criteria stipulated in BaSES (See Section 4.2.1 below); however, the predicted depth is less than observed, while predicted velocity is above observed values.

Although the flow rate and volume are calibrated, to fine tune the model the velocity needs to be decreased and the depth needs to increase. To accomplish this, Manning's "n" was changed from 0.013 to 0.020 for pipe segments upstream and downstream of the monitoring site based on field inspections showing attached deposits in this area. In addition, sediment depths were added to the model based on field observations, the flow meter site reports, and the presence of a "dead dog" in the depth vs. velocity scatter graph in Sliicer.com at this metering site. The significance of a "dead dog" is that there is minimum depth observed even with no flow, which is indicative of a downstream blockage, silt accumulation, or backwater from a downstream condition. After these changes were made, the predicted results more closely match the observed flow meter data, as shown in the plot of PA05A after calibration.





4.2.1 Calibration Criteria

According to Section 7.4 of the BaSES manual, the dry weather calibration should produce the following results:

- The modeled peak flow rate is within -10 to +20 percent of the observed
- The modeled volume of flow is within -10 to +20 percent of the observed
- The timing of the modeled peaks should be within 1 hour of the observed

4.2.2 Comparison of Metered and Modeled Results

All of the meters in the Patapsco sewershed meet the calibration requirements for volume of flow, as can be seen in Attachment 1, Dry Weather Observed vs. Predicted Plots. Although all of the meter sites were balanced for flow volumes, some of the meter sites could not be brought into agreement between predicted and observed values for velocity, depth and peak flow. These meters, and an explanation for their calibration difficulties, are listed below:

- PA01 – This meter is on a 24-inch sewer in manhole S55A2_003MH, approximately 350 feet upstream of the point where the 24-inch discharges into the Patapsco Interceptor, just upstream of the Patapsco WWTP Low Level Influent Pumping Station. It appears that the high water level of the wetwell produces backwater at this meter resulting in standing water and silt accumulation, which affects both depth and velocity readings. In addition, the "on/off" flow pattern is indicative of a small wetwell feeding large pumping units downstream of this meter, which may account for the flow patterns. This subsewershed is also heavily industrialized, which may result in the sporadic flow patterns that were observed. The flow volumes were calibrated within 12%; however, the peculiar flow pattern observed could not be replicated by the model.

- PA10 – The depth, velocity and peak flow rate could not be matched. This meter is located just downstream from documented blockages that required specialty heavy cleaning of the upstream sewers and manholes resulting in tons of debris removal. The debris was causing flow restriction, surcharging, standing water and likely sediment deposition. This meter is also upstream of the Patapsco River crossing, a possible source of infiltration. Because of surcharging in the downstream sewer, CCTV inspection was not possible. The observed velocity was much slower than predicted, and the predicted depths were less than those observed, which is logical given the obstructions in the sewer system. The flow volumes were calibrated within 1%; however, the observed depths, velocities and peak flow rate could not be replicated by the model.

- PA11 – The depth, velocity and peak flow rate could not be matched. This meter is located just upstream from documented blockages that required specialty heavy cleaning of the upstream sewers and manholes resulting in tons of debris removal. The debris was causing flow restriction, surcharging, standing water and likely sediment deposition. The observed velocity was much slower than predicted, and the predicted depths were less than those observed, which is logical given the obstructions in the sewer system. The flow volumes were calibrated within 4%; however, the observed depths, velocities and peak flow rates could not be replicated by the model.

- TSPA03 – This meter is also just upstream of the Patapsco WWTP Low Level Influent Pumping Station. It appears that the high water level of the wetwell produces backwater at this meter resulting in standing water and silt accumulation, which affects both depth and velocity readings. This sub-sewershed is also heavily industrialized, which may result in the sporadic flow patterns that were observed. The flow volumes were calibrated within 13%; however, the observed depths and velocities could not be replicated by the model.

4.2.3 QA/QC Analysis

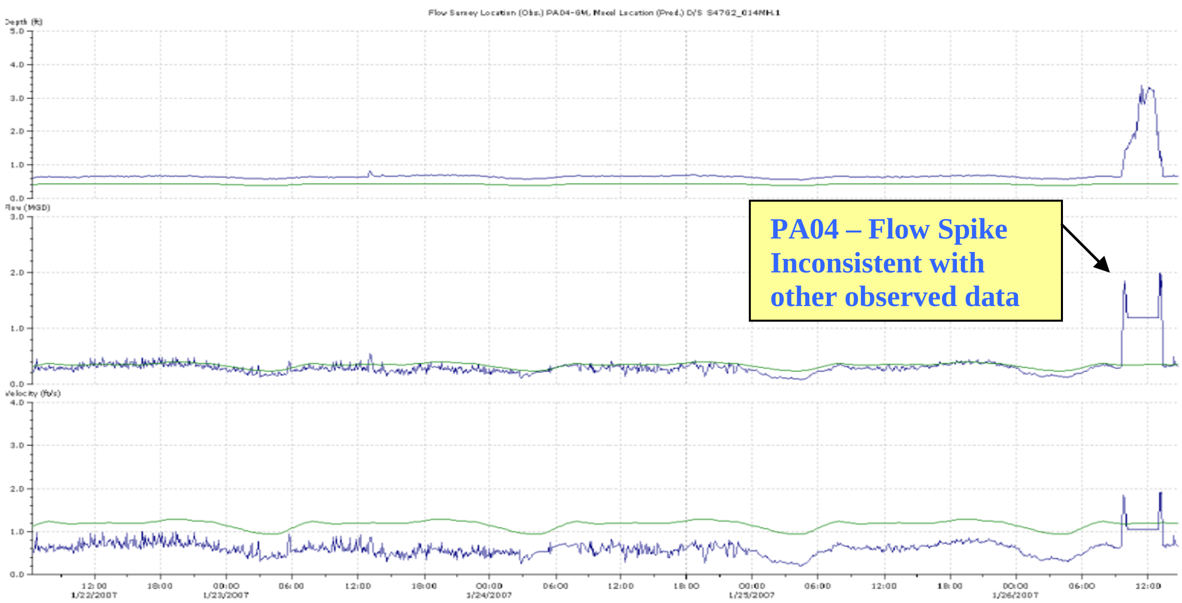
To assess the accuracy of the performance of the model compared to the observed data, the Observed vs. Predicted plots were reviewed. The shape and timing of the model hydrographs are compared to the observed flow and any major discrepancies were corrected by adjusting the diurnal curves. Depths and velocities were compared and the roughness factors and sediment depths, where indicated by field investigations or data analysis, were adjusted to more closely match the observed values.

The model simulations time period for the dry weather calibration was run for one week (1/20/2007 to 1/26/2007) and the predicted vs. observed flow volumes are totaled by InfoWorks for that time period. The percent differences from the predicted to the observed are show in Table 6, Model Volume Accuracy. As can be seen in the table, nearly all of the meters meet the requirements of BaSES manual. All of the meters are within 14%, with all but three meters under 8%, indicating that the model is well calibrated for dry weather flow.

TABLE 6
MODEL VOLUME ACCURACY (MG)

Flow Meter	Predicted	Observed	% Difference
BPA01	2.885	2.827	2
BPA02	3.995	4.081	2
BPA03	1.501	1.500	0
PA01	4.918	5.521	11
PA03	2.855	2.624	8
PA04	1.973	1.912	3
PA05	31.031	32.753	5
PA05A	20.322	18.989	7
PA06	7.057	6.694	5
PA07	4.833	4.643	4
PA08	1.019	0.882	14
PA09	7.634	7.203	6
PA10	8.411	8.504	1
PA11	4.216	4.401	4
PA12	1.230	1.252	2
TSPA03	37.942	43.049	12

Comparisons were not performed for peak flow rates because for many of the meters, there is an unusual spike in the observed flow rates, which would make direct comparisons between the predicted and observed flows difficult. The curves were visually inspected to ensure all peak flow rates generally matched. See the graph below for an example of an anomalous observed peak.



4.3 Wet-Weather Calibration

Following completion of the dry weather calibration, wet weather calibration was initiated. As stated in Section 2.4, the capture coefficient, or percent of rainfall “captured” during a storm, is determined by analysis of flow measurement data using Sliicer.com. After estimating the rainfall-induced flow for a number of storms, RDII volumes are calculated and plotted versus rainfall depth (Q vs. i) at each meter site. R, the capture coefficient, is proportional to the slope of the regression line between RDII and rainfall depth. Capture coefficients were developed from Sliicer.com and entered into the model’s subcatchments as “Fixed Runoff Coefficients”. The first model runs were based on InfoWorks’ default values for basin slope and width and an initial value of 0.015 for runoff routing values (i.e., roughness factors). Each subsewershed also had a uniform runoff coefficient across an entire land use.

After reviewing the results and looking at all of the global storm events, different subcatchment parameters were adjusted to more accurately predict the flow meter responses. Based on a sensitivity analysis comparing predicted or modeled flow to the observed flow as measured by the flow monitors, adjustments to different subcatchment parameters were made. For example, if the predicted flow volume was less than observed, the runoff coefficients could be increased. If the timing of peaks was off, the slope and the runoff routing value could be adjusted. To adjust the recovery duration and peak timing, the basin width could be adjusted.

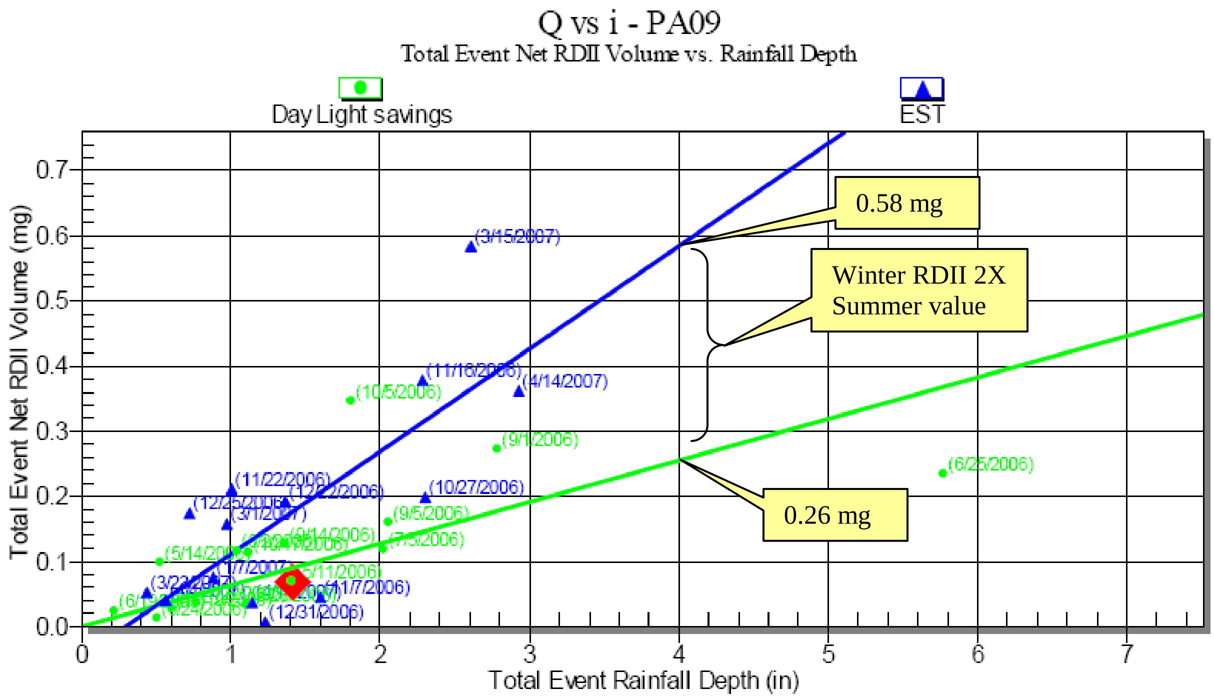
4.3.1 Calibration Criteria

According to the BaSES manual, the following are guidelines for the wet weather calibration:

- The modeled peak flow rate, in million gallons per day (mgd), should be within -10 percent and +25 percent of the observed peak rate
- The modeled volume of flow, in million gallons (MG), should be within +20 percent and -10 percent of the observed
- The modeled depth of flow in surcharged sewers should be within +18 inches and -4 inches in sewers 21 inches in diameter and larger and within +6 inches and -4 inches in sewers smaller than 21 inches in diameter compared to the observed depth
- The modeled depth of flow at unsurcharged critical points in the system should be within 4 inches of the observed
- The shape and timing of the modeled hydrographs should be similar to the observed.

4.3.2 Comparison of Metered and Modeled Results

When looking at the observed (metered) and predicted (modeled) flows and RDII volumes, there are notable differences between “summer” (Day Light Savings Time) and “winter” (Eastern Standard Time) storms. Summer storms are typically of shorter duration and higher intensity than winter events. In addition, the ground is usually dryer and the water table is usually lower in summer compared to winter. This means more precipitation is stored in the ground before runoff occurs resulting in less runoff from a given storm event in summer compared to winter storms. Conversely, with the ground wetter and the water table higher, more runoff occurs from the same rain event in winter than in summer. Because of this, more RDII, the wet weather component of wastewater, usually enters the sewers during winter storm events as compared to summer storms. Because of these observations, it would be difficult to calibrate the model to accurately reflect both winter and summer storm events. The graph below demonstrates these observations:



The winter (EST) storms are shown by blue triangles and the summer (DST) storms are shown with green circles. A regression line is fitted between these points producing the blue line for winter storms and the green line for summer storms. From this plot, it can be seen that more than twice the volume of RDII enters the sewers during the winter as compared to the summer for the same depth of rainfall during a storm event. This is especially true for the larger storm events. This observation led to difficulties in trying to calibrate the model to accurately predict both type of storm events. If the model were to be calibrated only to summer events, the volume of RDII would be understated in winter and potential capacity deficiencies in the system may not be fully identified. Conversely, if the model were only calibrated to the winter storms, the volume of RDII would be overstated for summer events, resulting in the possibility of identifying capacity improvements that may be overly conservative in their sizing. As a compromise, all storms were used to develop the R value, or capture coefficient, in the plots of Q vs. i for each metering site. By using this method, the model will over-predict summer storms, and under-predict winter storms, but to a lesser amount than if only summer or winter storms were used to develop R values. Using this approach, the calibration guidelines are generally met.

4.3.3 QA/QC Analysis

To assess the validity of the model compared to the observed flow meter responses, a series of statistical comparison plots were produced as outlined in BaSES. See Appendix 1 for a summary of observed versus predicted responses for each meter and graphs comparing observed versus predicted volumes and peak flow rates. The values used in comparing the volumes are based on the durations of the global storms shown in Table 2, to include time before the storm event for the pre-compensation period (usually 24 hours) plus the recovery time after the storm to allow the hydrograph to return to its normal, diurnal pattern. On the statistical comparison plots, a regression line with an R^2 value equal to 1.00 indicates a perfect fit between the modeled and observed peak flows and volumes. Lower R^2 values mean less agreement between observed vs. simulated flow volumes. If the intercept of the regression line is close to zero, then the modeled storm event volumes and peak flow rates are not biased (i.e., consistently over-predicting or under-predicting) with respect to the observed volumes and peak flow rates. When using all storms to develop the "R" value as discussed above, regression lines tend to vary from those parameters. The summer storms, which are usually over-predicted, have less I/I per rain depth than the winter storms, which are under-predicted. This skews the graph away from the ideal situation. The wet weather calibration produced a high degree of agreement between observed and predicted volumes at most flow meters. On PA03 and PA08, although flow volume was within calibration parameters, peak flows were under predicted. To increase the predicted flows, the subcatchment width was increased. Even with this adjustment, PA08 does not show good congruence between predicted and observed peaks; however, the flow volume in this basin is relatively small and well below the capacity of the piping system. Conversely, on PA05A, PA10 and TSPA03, the peak flows were over predicted, although flow volume was acceptable. To reduce peak flow rates, the subcatchment widths for these basins were decreased. PA05A is also influenced by the Brooklyn Pumping Station, which has variable speed pumps controlled by programmable logic controllers (PLC's). The PID (proportional/integral/differential) field in InfoWorks was adjusted to improve predicted results from the variable speed pumping units. Improvements in the calibration of PA10 also resulted in improvement at PA05A since PA05A includes flow from PA10. PA12 had peak flow rates and volumes that were under predicted. To improve this condition, the fixed runoff coefficient was increased over earlier simulations, and a second runoff surface was created with a 0.75-inch initial loss to simulate increased RDII for larger storms. Despite these adjustments, PA12 remains problematic, with observed peak flows and volumes well above the predicted results. Reviewing the hydrograph for PA12 for the 6/25/2006 storm, which is the largest storm in inches of precipitation and the second longest storm in duration during the flow monitoring period, shows observed volumes over three times higher than the predicted, despite the calibration attempts. Reviewing the 7/5/2006 storm, which had the third highest precipitation depth, shows observed volumes also over 3 times higher than the predicted. The meter at PA10 measures the flow generated in sub-basins PA10, PA11 and PA12. Doing a simple flow balance for the 6/25/2006 and 7/5/2006 storms shows the sum of PA11 and PA12 alone exceed the observed values at PA10. Given this, the observed flow data from PA12 appear to be unreliable. Even when the differences between observed vs. modeled volumes and peaks were greater than the recommended guidelines from BaSES, the shape of the hydrograph and timing of the peak events were generally in congruence after calibration.

The high intensity design storms to be used in the capacity analysis are more typical of summer type storms than winter storms. With the Patapsco model calibrated using all storms in the development of capture coefficients, this provides a somewhat conservative capacity estimate, while not over-designing alternatives as compared to a model that extremely over-predicts the summer storms to meet the winter storm runoff volumes.

In addition, the observed vs. predicted graphs generated by InfoWorks were reviewed to assess the shape and timing of the hydrographs. Attachment 2 on the included CD contains PDF files of the wet weather hydrographs for each meter and each storm event.

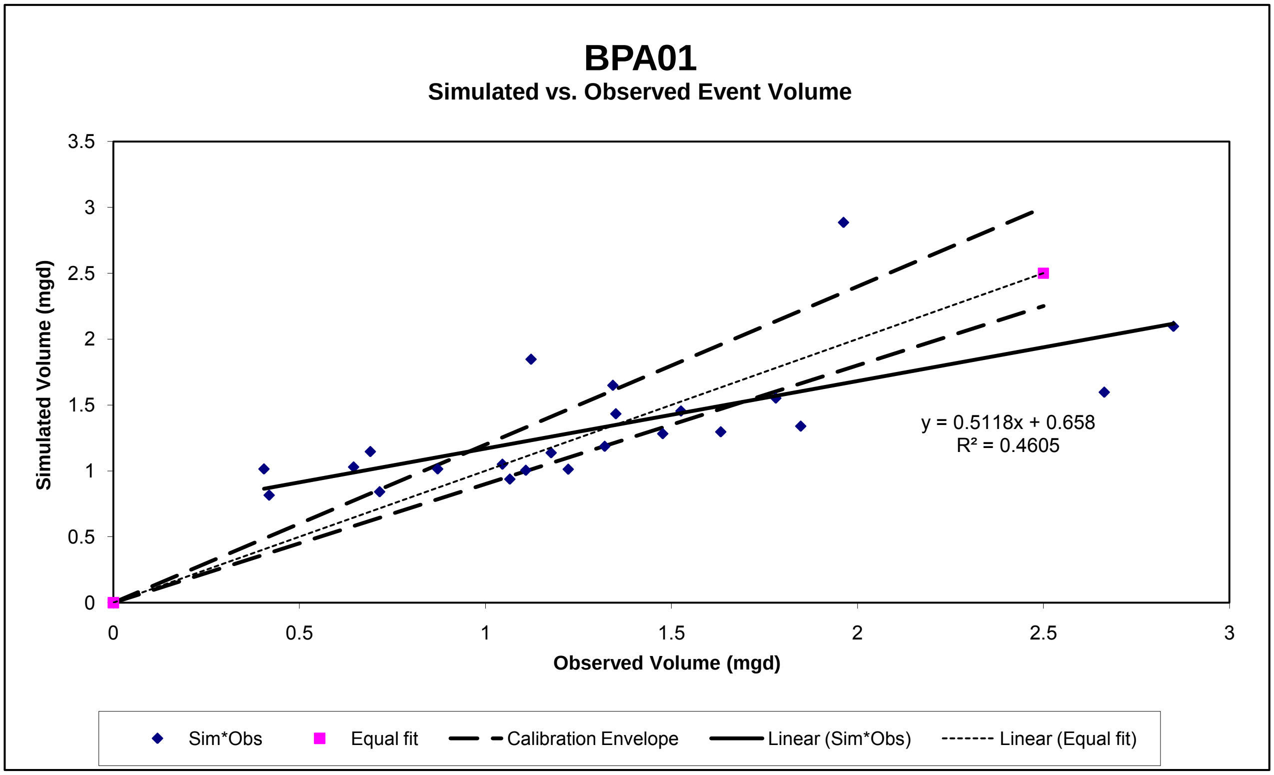
5.0 SUMMARY AND CONCLUSIONS

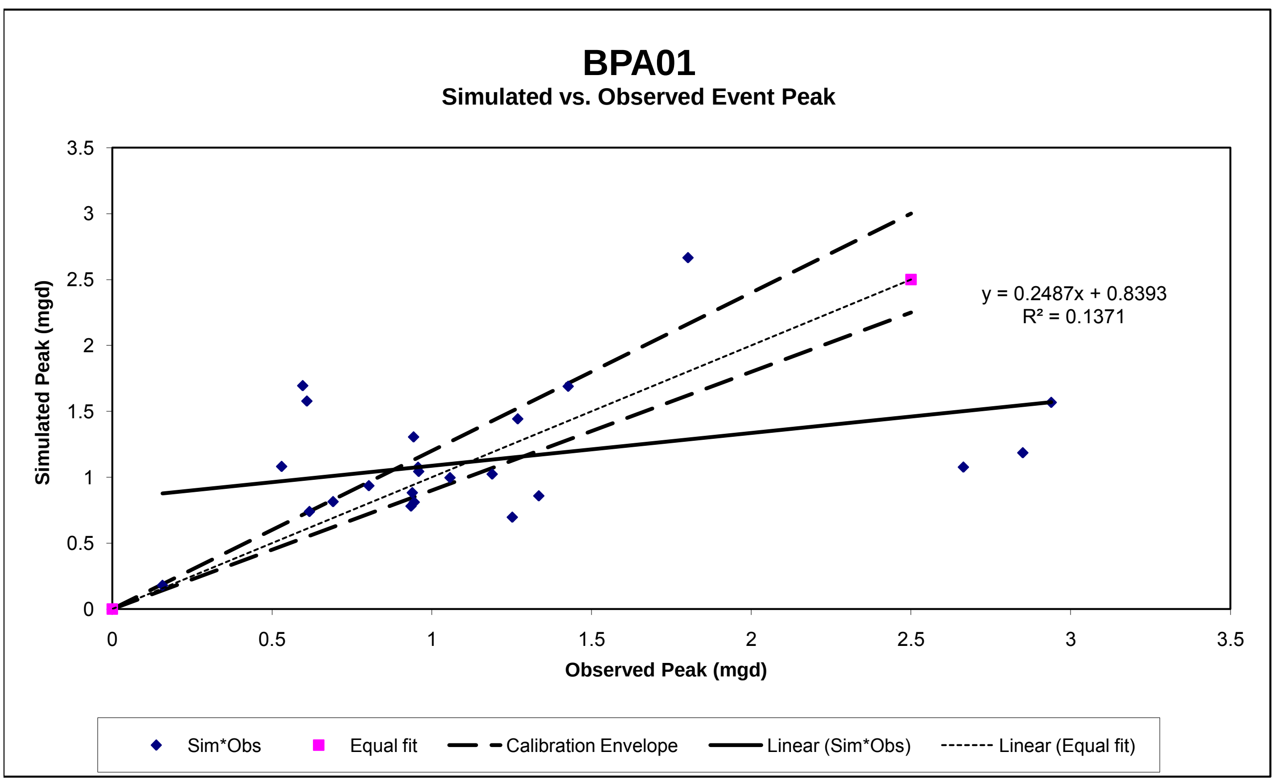
The hydraulic model of the Patapsco Sewershed has been built in accordance with the Consent Decree and as outlined in the BaSES manual. The network was built from field verified GIS information and the flow inputs are based on 17 individual flow meters installed for over one year. Dry weather calibration of storm volumes was completed without having to use any unrealistic conditions or assumptions, such as using an unusually high or low Manning's "n". The wet weather calibration utilized all storms to develop "median" R values to represent both winter and summer storm events. To improve calibration results, subcatchment parameters at several meters were adjusted. When looking at all of the modeled storms as a whole and balancing parameters that were initially out of calibration, the model provides a realistic prediction of the hydraulic performance of the Patapsco sewershed during wet weather events. Based on these facts and the provided supporting material, the Patapsco hydraulic model has been deemed "calibrated" and the baseline and future flows capacity assessments can begin.

Appendix 1

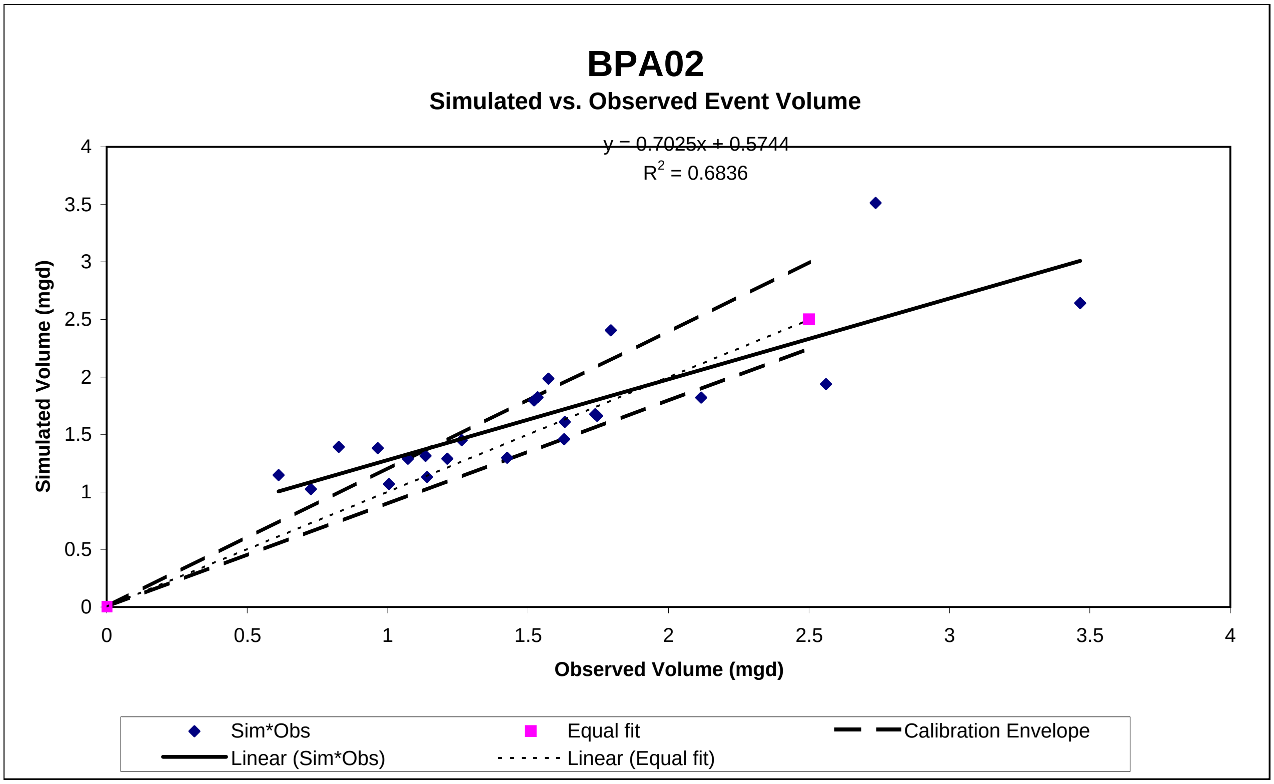
Wet Weather Observed Vs. Predicted Statistics and Graphs

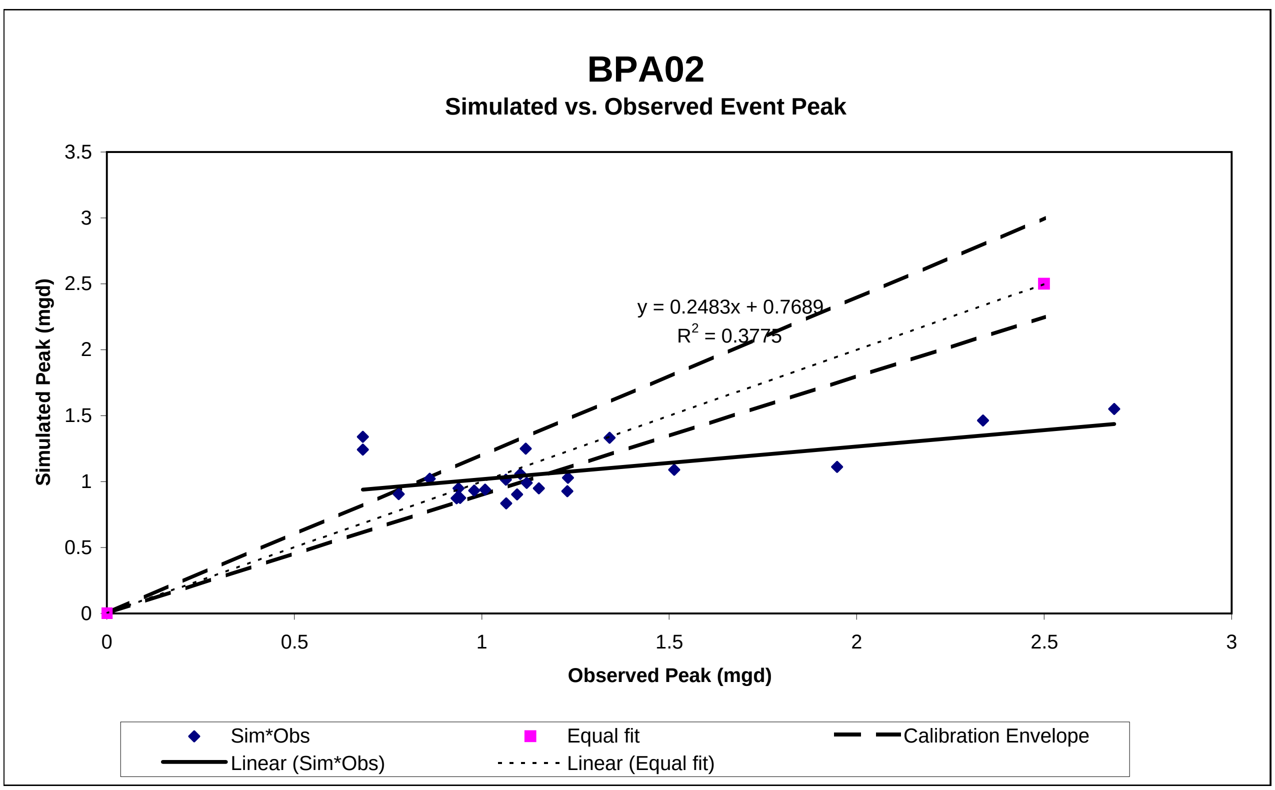
Storm Events	BPA01								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	0.405	1.014	150%	0.596	1.695	184%	0.454	0.674	0.220
May 14, 2006									0.000
June 2, 2006	0.419	0.815	95%	0.53	1.082	104%	0.411	0.534	0.123
June 19, 2006									
June 24, 2006									
June 25, 2006	1.963	2.886	47%	1.427	1.69	18%	0.925	0.673	-0.252
July 5, 2006	1.123	1.847	64%	1.269	1.443	14%	0.818	0.613	-0.205
July 22, 2006	0.646	1.029	59%	0.617	0.74	20%	0.461	0.45	-0.011
August 7, 2006	0.691	1.146	66%	0.609	1.578	159%	0.463	0.648	0.185
September 1, 2006	1.343	1.649	23%	0.943	1.306	38%	0.508	0.589	0.081
September 5, 2006									
September 14, 2006	1.351	1.433	6%	0.959	1.044	9%	0.499	0.515	0.016
September 28, 2006	0.872	1.014	16%	0.803	0.936	17%	0.455	0.502	0.047
October 5, 2006	1.526	1.454	-5%	0.957	1.076	12%	0.469	0.532	0.063
October 17, 2006	1.046	1.05	0%	0.157	0.18	15%	0.487	0.493	0.006
October 19, 2006									
October 27, 2006	1.848	1.339	-28%	2.85	1.186	-58%	0.852	0.563	-0.289
November 7, 2006	1.321	1.186	-10%	1.189	1.024	-14%	0.503	0.519	0.016
November 16, 2006	1.781	1.552	-13%	1.802	2.666	48%	1.712	0.881	-0.831
November 22, 2006	1.223	1.012	-17%	0.939	0.883	-6%	0.497	0.491	-0.006
December 22, 2006	1.177	1.137	-3%	0.945	0.811	-14%	0.477	0.472	-0.005
January 1, 2007	1.066	0.937	-12%	1.057	0.997	-6%	0.488	0.513	0.025
January 7, 2007	1.477	1.282	-13%	0.935	0.781	-16%	0.472	0.463	-0.009
March 1, 2007	1.633	1.296	-21%	1.335	0.859	-36%	0.59	0.485	-0.105
March 15, 2007	2.664	1.597	-40%	2.664	1.077	-60%	1.192	0.533	-0.659
March 23, 2007									
April 4, 2007	0.716	0.841	17%	0.691	0.815	18%	0.425	0.473	0.048
April 11, 2007	1.109	1.004	-9%	1.252	0.697	-44%	0.658	0.437	-0.221
April 14, 2007	2.85	2.097	-26%	2.939	1.568	-47%	1.698	0.646	-1.052


BPA01
Simulated vs. Observed Event Volume
Simulated Volume (mgd)
Observed Volume (mgd)
y = 0.5118x + 0.658
R² = 0.4605
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

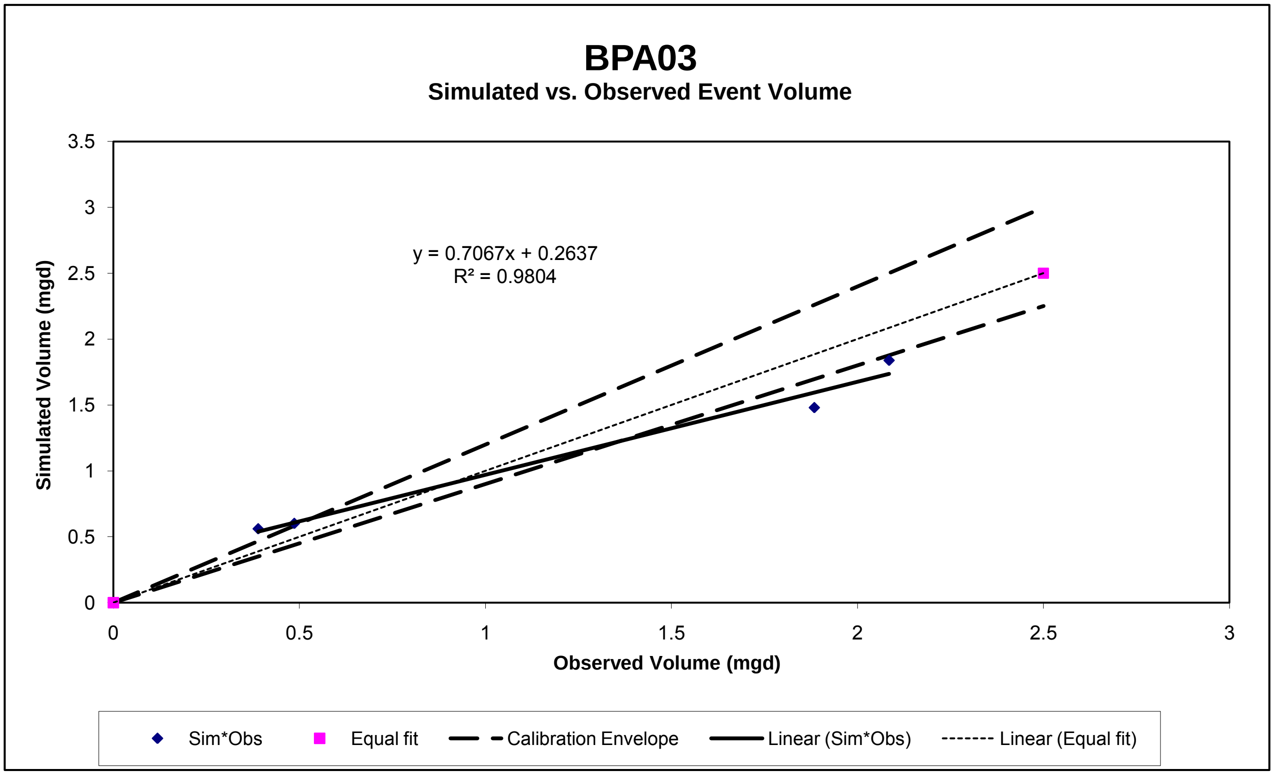

BPA01
Simulated vs. Observed Event Peak
Simulated Peak (mgd)
Observed Peak (mgd)
y = 0.2487x + 0.8393
R² = 0.1371
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

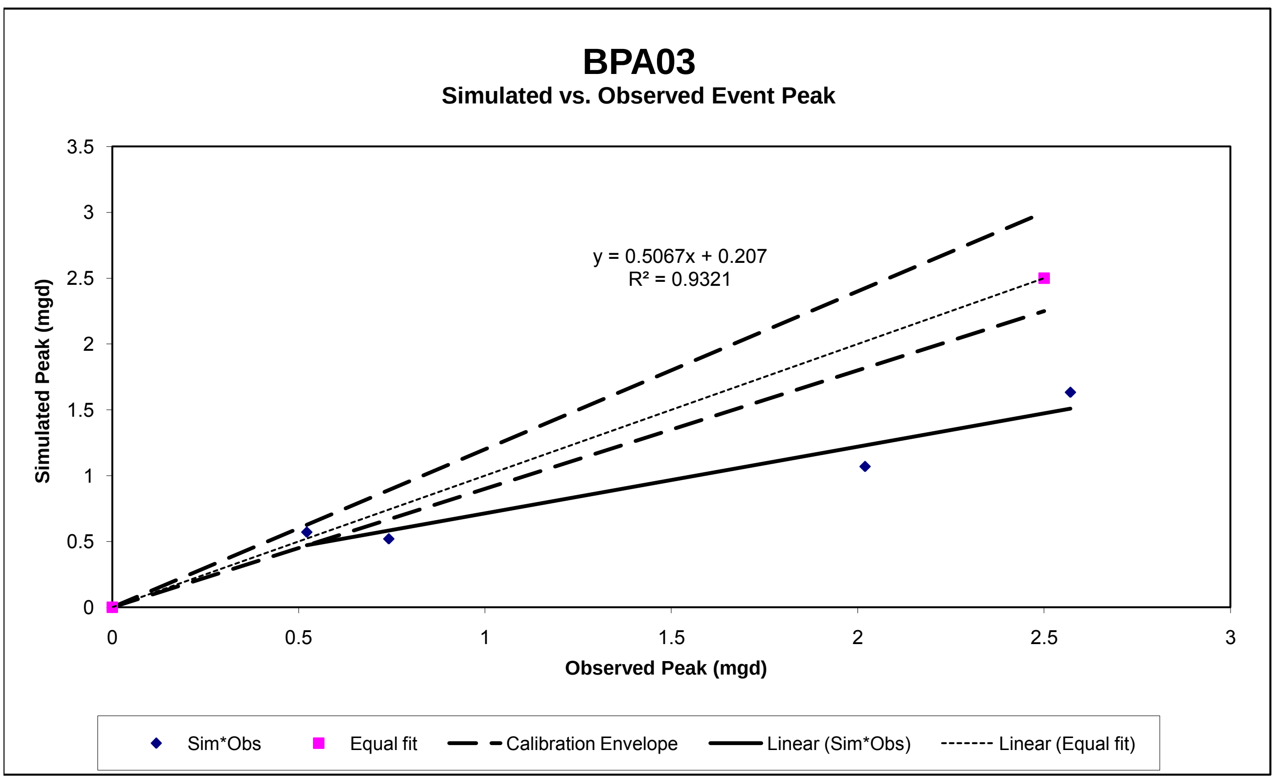
Storm Events	BPA02								
	Volume (mg)(-10% to+20%)			**Peak Flow (mgd)(-10%to+25%)**			**Depth (ft.)(-0.25'to+0.5')**		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	0.612	1.146	87%	0.683	1.339	96%	0.497	0.489	-0.008
May 14, 2006									
June 2, 2006	0.727	1.023	41%	0.861	1.023	19%	0.517	0.427	-0.090
June 19, 2006									
June 24, 2006									
June 25, 2006	2.737	3.512	28%	1.341	1.332	-1%	0.613	0.487	-0.126
July 5, 2006	1.795	2.404	34%	1.064	1.014	-5%	0.552	0.425	-0.127
July 22, 2006	0.965	1.381	43%	0.778	0.905	16%	0.476	0.402	-0.074
August 7, 2006	0.826	1.392	69%	0.683	1.243	82%	0.45	0.471	0.021
September 1, 2006	1.573	1.984	26%	1.117	1.25	12%	0.545	0.472	-0.073
September 5, 2006									
September 14, 2006	1.534	1.822	19%	1.12	0.991	-12%	0.528	0.42	-0.108
September 28, 2006	1.072	1.288	20%	0.938	0.95	1%	0.486	0.412	-0.074
October 5, 2006	1.521	1.796	18%	1.103	1.059	-1%	0.523	0.435	-0.088
October 17, 2006	1.135	1.314	16%	1.009	0.939	-7%	0.521	0.409	-0.112
October 19, 2006									
October 27, 2006	1.631	1.61	-1%	1.513	1.09	-28%	0.62	0.441	-0.179
November 7, 2006	1.628	1.458	-10%	1.23	1.029	-16%	0.604	0.428	-0.176
November 16, 2006	2.116	1.821	-14%	2.687	1.552	-42%	0.805	0.526	-0.279
November 22, 2006	1.426	1.296	-9%	1.228	0.928	-24%	0.557	0.407	-0.150
December 22, 2006	1.264	1.451	15%	1.094	0.903	-17%	0.526	0.401	-0.125
January 1, 2007	1.141	1.13	-1%	1.152	0.948	-18%	0.537	0.411	-0.126
January 7, 2007	1.746	1.663	-5%	0.942	0.877	-7%	0.506	0.396	-0.110
March 1, 2007	1.739	1.675	-4%	0.98	0.932	-5%	0.511	0.408	-0.103
March 15, 2007	2.561	1.937	-24%	1.948	1.111	-43%	0.674	0.445	-0.229
March 23, 2007									
April 4, 2007	1.005	1.068	6%	0.933	0.873	-6%	0.543	0.395	-0.148
April 11, 2007	1.213	1.29	6%	1.065	0.836	-22%	0.522	0.386	-0.136
April 14, 2007	3.465	2.642	-24%	2.337	1.463	-37%	0.788	0.511	-0.277


BPA02
Simulated vs. Observed Event Volume
y = 0.7025x + 0.5744
R^2 = 0.6836
Simulated Volume (mgd)
Observed Volume (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
4
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

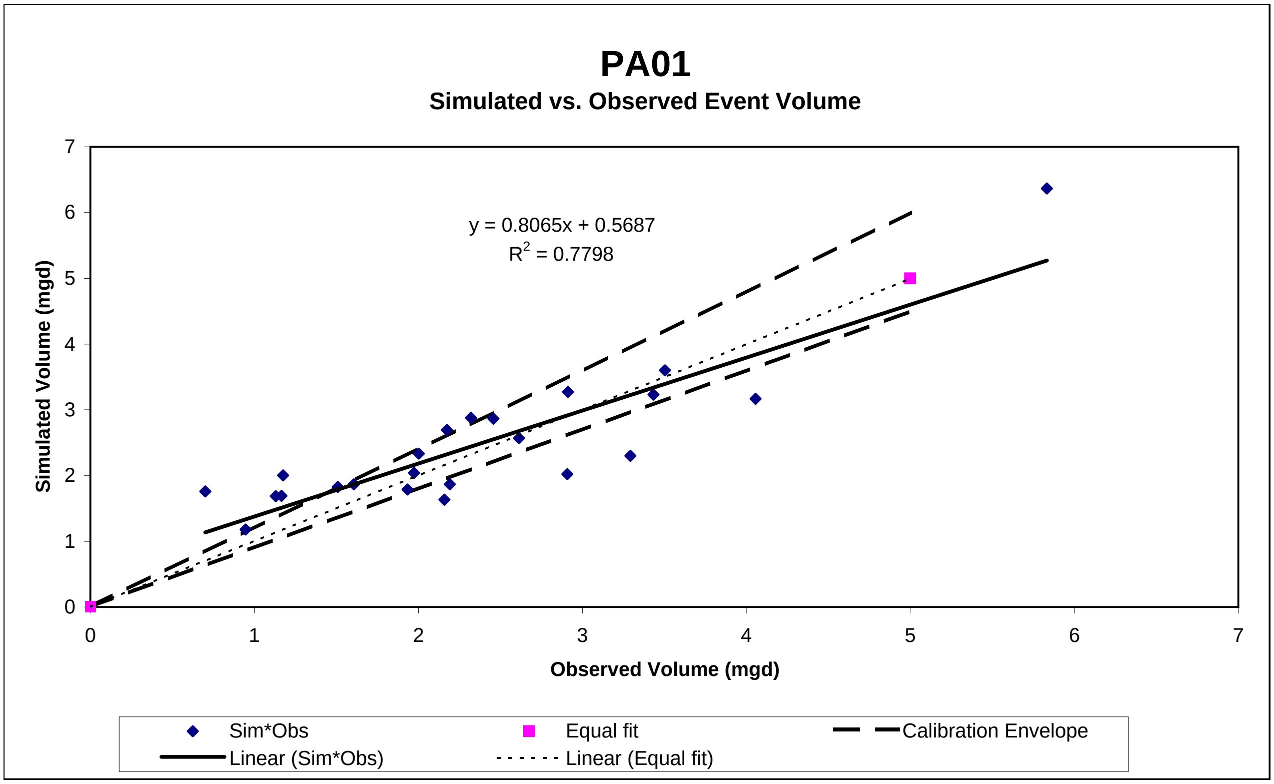

BPA02
Simulated vs. Observed Event Peak
y = 0.2483x + 0.7689
R^2 = 0.3775
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

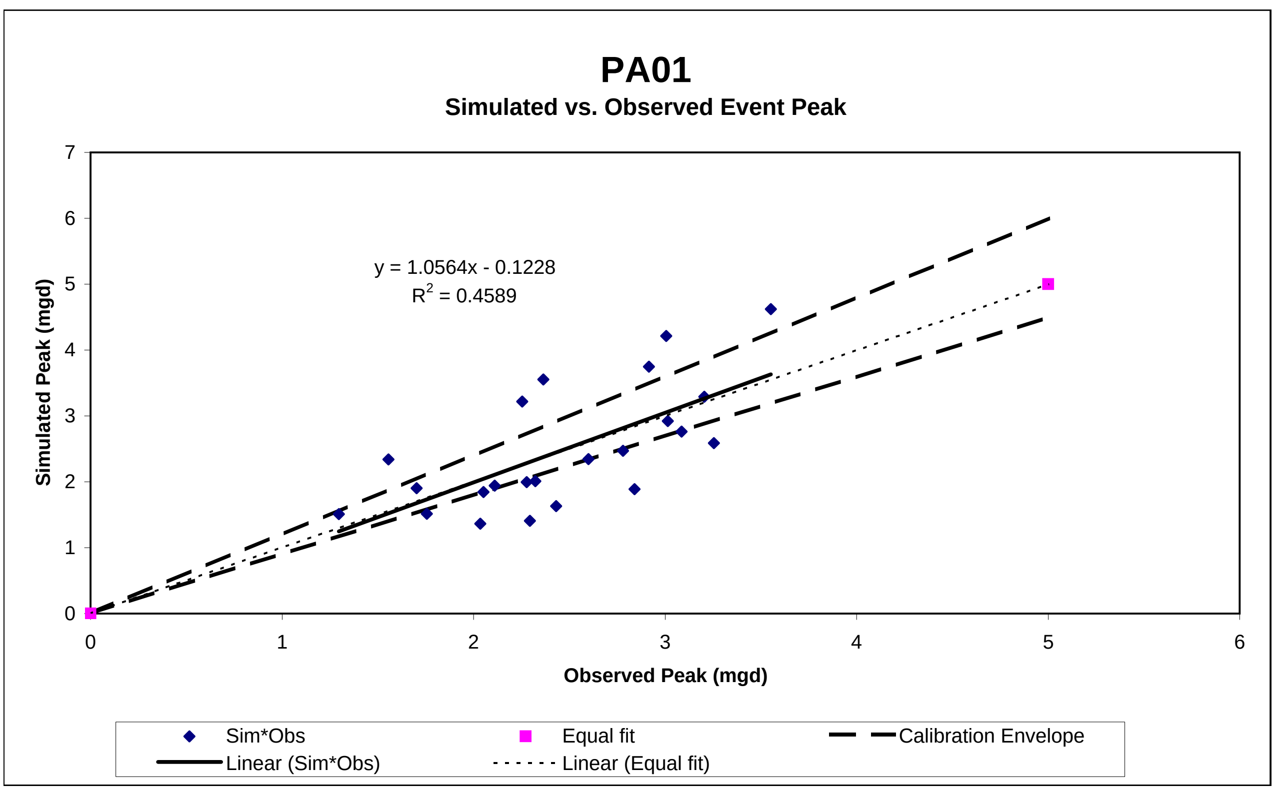
	BPA03								
Storm Events	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006									
May 14, 2006									
June 2, 2006									
June 19, 2006									
June 24, 2006									
June 25, 2006									
July 5, 2006									
July 22, 2006									
August 7, 2006									
September 1, 2006									
September 5, 2006									
September 14, 2006									
September 28, 2006									
October 5, 2006									
October 17, 2006									
October 19, 2006									
October 27, 2006									
November 7, 2006									
November 16, 2006									
November 22, 2006									
December 22, 2006									
January 1, 2007									
January 7, 2007									
March 1, 2007									
March 15, 2007	1.884	1.48	-21%	2.02	1.07	-47%	0.693	0.521	-0.172
March 23, 2007									
April 4, 2007	0.389	0.559	44%	0.522	0.571	9%	0.334	0.368	0.034
April 11, 2007	0.486	0.6	23%	0.742	0.52	-30%	0.384	0.354	-0.030
April 14, 2007	2.085	1.839	-12%	2.571	1.634	-36%	1.203	0.785	-0.418


BPA03
Simulated vs. Observed Event Volume
y = 0.7067x + 0.2637
R² = 0.9804
Simulated Volume (mgd)
Observed Volume (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

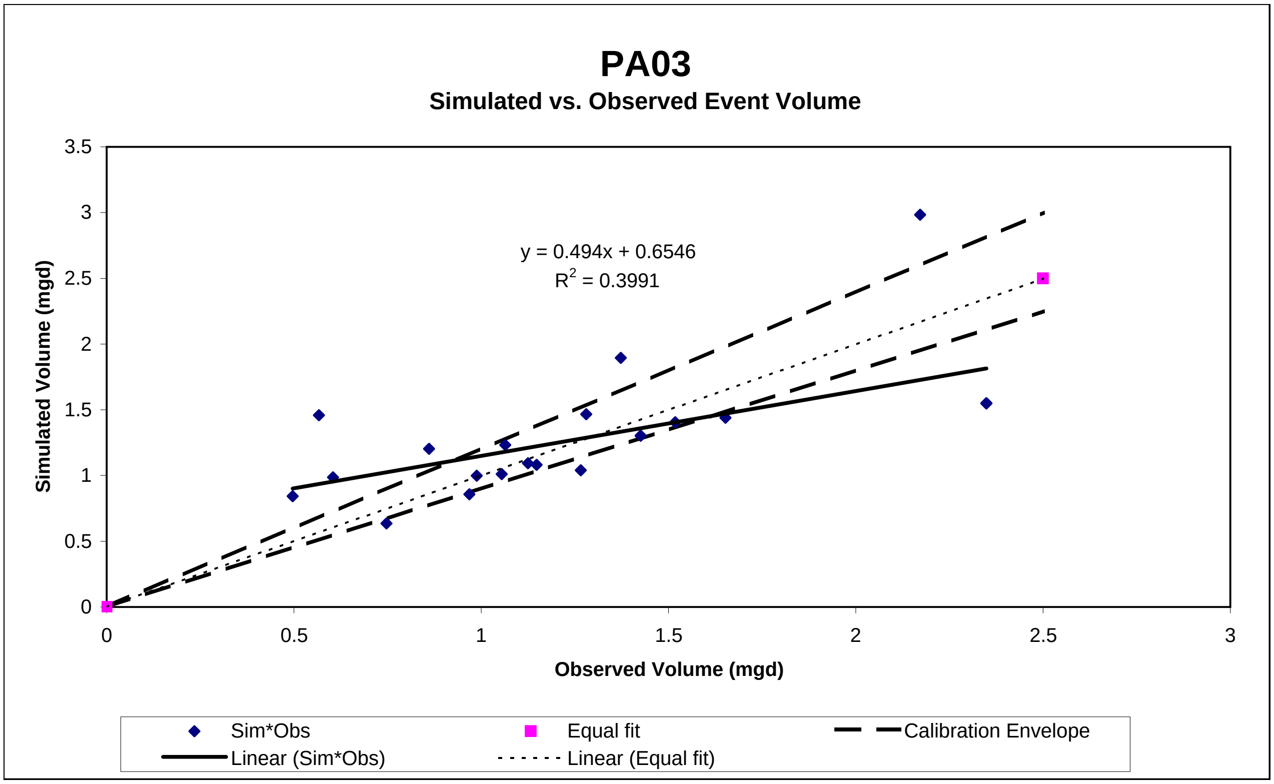

BPA03
Simulated vs. Observed Event Peak
y = 0.5067x + 0.207
R² = 0.9321
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA01								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	1.509	1.826	21%	2.365	3.554	50%	1.619	4.084	2.465
May 14, 2006									0.000
June 2, 2006	1.166	1.691	45%	2.254	3.218	43%	1.588	3.364	1.776
June 19, 2006									0.000
June 24, 2006									0.000
June 25, 2006	5.832	6.369	9%	3.006	4.215	40%	2.099	6.515	4.416
July 5, 2006	3.504	3.602	3%	2.915	3.746	29%	1.876	5.073	3.197
July 22, 2006	1.175	2.003	70%	2.322	2.01	-13%	1.735	2.316	0.581
August 7, 2006	0.701	1.758	151%	2.111	1.943	-8%	2.093	2.947	0.854
September 1, 2006	2.321	2.878	24%	3.086	2.763	-10%	2.31	2.119	-0.191
September 5, 2006									0.000
September 14, 2006	2.457	2.863	17%	2.277	1.993	-12%	1.618	2.117	0.499
September 28, 2006	1.606	1.864	16%	2.051	1.844	-10%	1.569	2.243	0.674
October 5, 2006	2.175	2.694	24%	2.599	2.344	-10%	1.671	2.156	0.485
October 17, 2006	2.159	1.633	-24%	2.431	1.633	-33%	1.653	1.774	0.121
October 19, 2006									0.000
October 27, 2006	2.613	2.569	-2%	3.014	2.924	-3%	1.944	2.852	0.908
November 7, 2006	3.294	2.298	-30%	3.255	2.585	-21%	1.814	2.918	1.104
November 16, 2006	3.433	3.231	-6%	3.552	4.62	30%	4.853	11.227	6.374
November 22, 2006	2.192	1.866	-15%	2.294	1.408	-39%	1.599	1.211	-0.388
December 22, 2006	1.973	2.04	3%	1.756	1.513	-14%	1.49	1.321	-0.169
January 1, 2007	1.131	1.684	49%	1.555	2.338	50%	1.524	2.943	1.419
January 7, 2007	0.947	1.179	24%	1.297	1.509	16%	1.574	1.7	0.126
March 1, 2007	2.908	2.022	-30%	2.84	1.888	-34%	1.916	1.675	-0.241
March 15, 2007	4.057	3.166	-22%	2.781	2.471	-11%	1.67	1.762	0.092
March 23, 2007									0.000
April 4, 2007	2.002	2.335	17%	1.703	1.901	12%	1.45	2.282	0.832
April 11, 2007	1.934	1.79	-7%	2.035	1.365	-33%	1.905	1.219	-0.686
April 14, 2007	2.913	3.272	12%	3.204	3.291	3%	5.088	2.642	-2.446

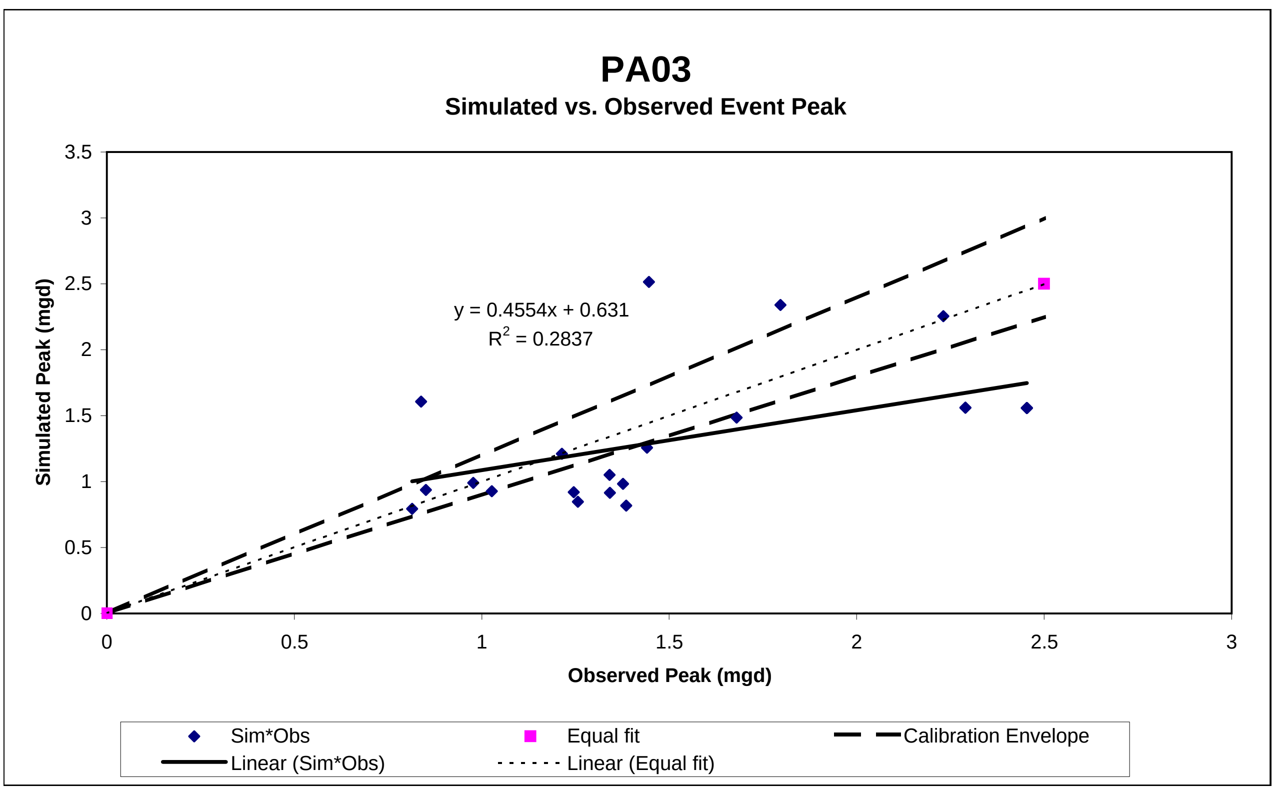

PA01
Simulated vs. Observed Event Volume
y = 0.8065x + 0.5687
R^2 = 0.7798
Simulated Volume (mgd)
Observed Volume (mgd)
0
1
2
3
4
5
6
7
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)


PA01
Simulated vs. Observed Event Peak
y = 1.0564x - 0.1228
R^2 = 0.4589
Simulated Peak (mgd)
Observed Peak (mgd)
0
1
2
3
4
5
6
7
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA03								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	1.426	1.302	-9%	2.29	1.56	-32%	1.237	0.79	-0.447
May 14, 2006									0.000
June 2, 2006	0.497	0.843	70%	0.838	1.606	92%	0.712	0.801	0.089
June 19, 2006									0.000
June 24, 2006									0.000
June 25, 2006	2.172	2.984	37%	1.446	2.515	74%	1.165	1.608	0.443
July 5, 2006	1.373	1.896	38%	1.797	2.341	30%	1.185	1	-0.185
July 22, 2006	0.604	0.987	63%	0.814	0.793	-3%	0.705	0.591	-0.114
August 7, 2006	0.861	1.202	40%	2.231	2.255	1%	1.656	1.29	-0.366
September 1, 2006	1.28	1.467	15%	1.68	1.486	-12%	0.986	0.768	-0.218
September 5, 2006									0.000
September 14, 2006	1.652	1.439	-13%	1.341	1.05	-22%	0.779	0.657	-0.122
September 28, 2006	0.988	0.999	1%	1.377	0.983	-29%	0.79	0.638	-0.152
October 5, 2006	1.518	1.406	-7%	1.214	1.211	0%	0.749	0.706	-0.043
October 17, 2006	1.055	1.012	-4%	1.027	0.928	-10%	0.748	0.626	-0.122
October 19, 2006									0.000
October 27, 2006	1.426	1.302	-9%	2.29	1.56	-32%	1.237	0.79	-0.447
November 7, 2006	2.349	1.548	-34%	2.454	1.558	-37%	1.281	0.79	-0.491
November 16, 2006	2.349	1.548	-34%	2.454	1.558	-37%	1.281	0.79	-0.491
November 22, 2006	1.266	1.041	-18%	1.342	0.916	-32%	0.829	0.623	-0.206
December 22, 2006	1.125	1.094	-3%	1.256	0.846	-33%	0.841	0.606	-0.235
January 1, 2007	0.968	0.857	-11%	1.441	1.257	-13%	0.909	0.717	-0.192
January 7, 2007	0.747	0.636	-15%	1.385	0.819	-41%	0.802	0.599	-0.203
March 1, 2007	1.148	1.082	-6%	1.245	0.921	-26%	0.968	0.624	-0.344
March 15, 2007	2.349	1.548	-34%	2.454	1.558	-37%	1.281	0.79	-0.491
March 23, 2007									0.000
April 4, 2007	1.064	1.232	16%	0.851	0.937	10%	0.768	0.628	-0.140
April 11, 2007	0.567	1.46	157%	0.977	0.99	1%	0.883	0.557	-0.326
April 14, 2007	2.349	1.548	-34%	2.454	1.558	-37%	1.281	0.79	-0.491

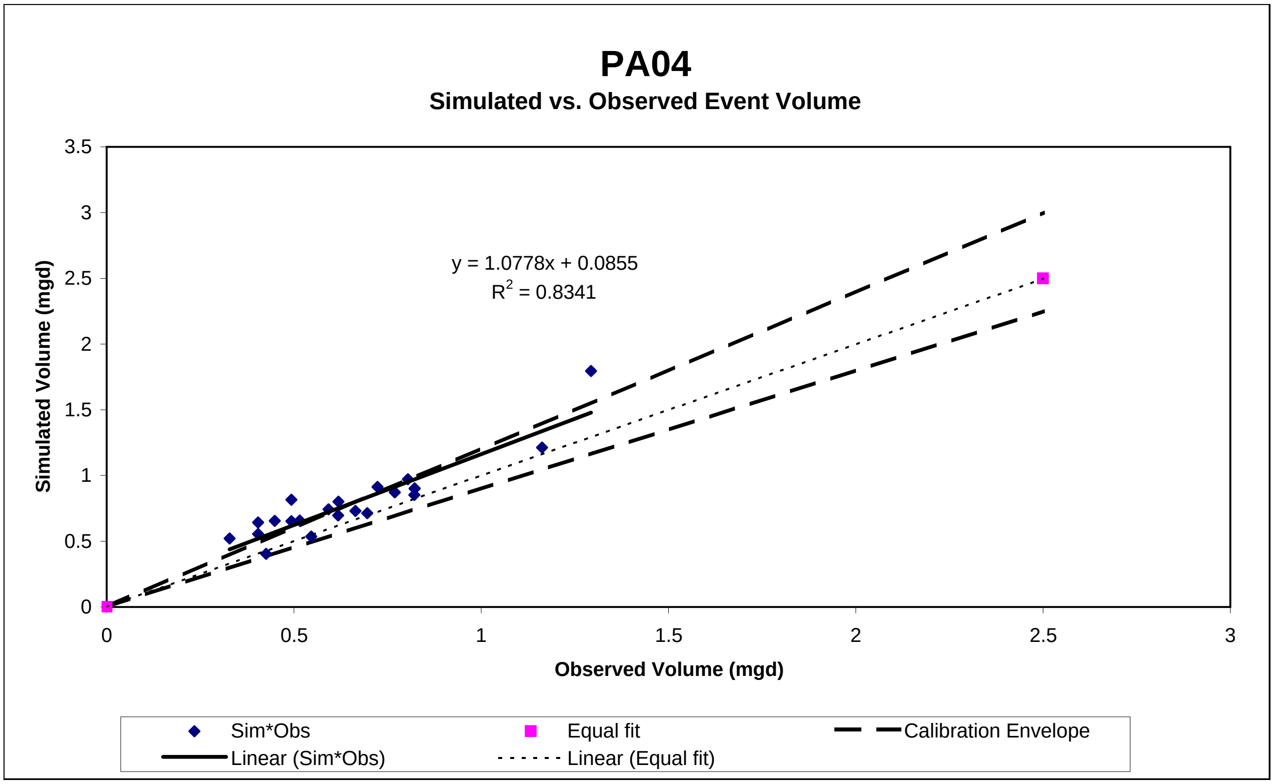


PA03
Simulated vs. Observed Event Volume
y = 0.494x + 0.6546
R2 = 0.3991
Simulated Volume (mgd)
Observed Volume (mgd)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

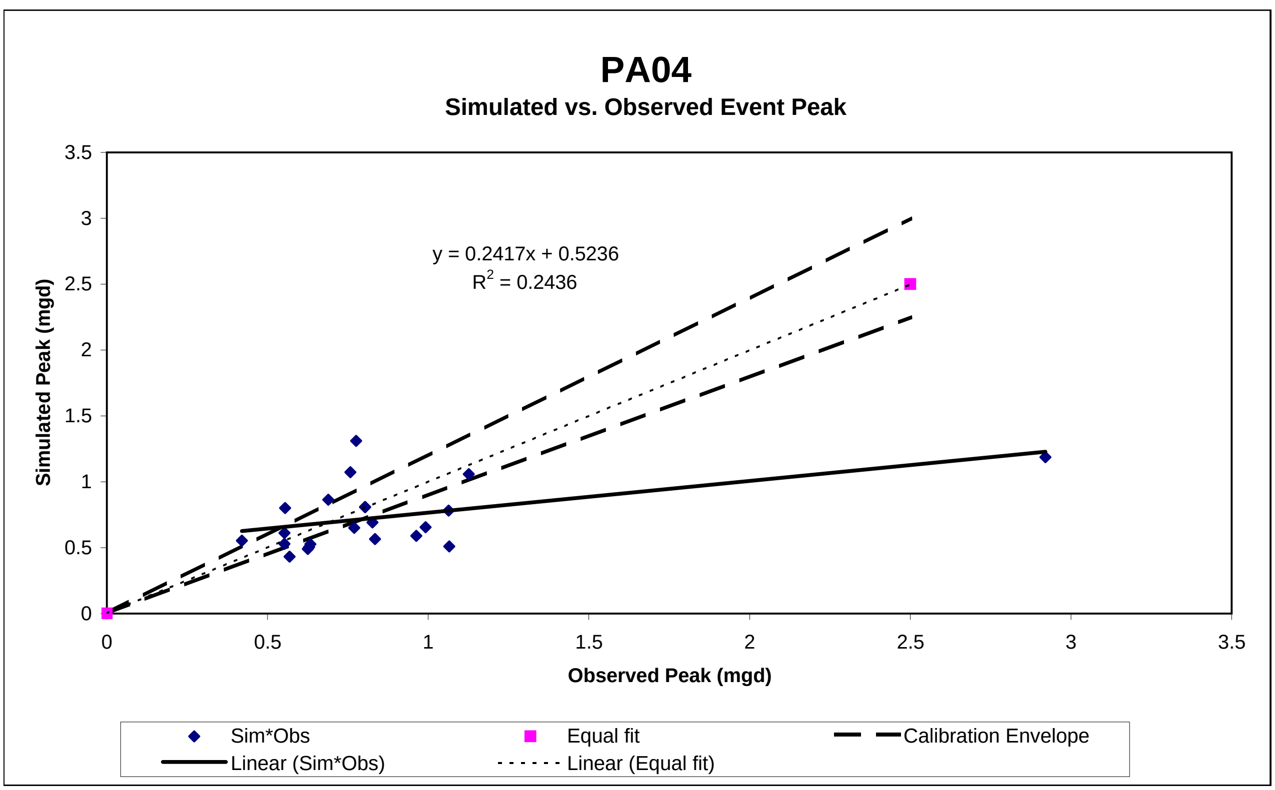


PA03
Simulated vs. Observed Event Peak
y = 0.4554x + 0.631
R2 = 0.2837
Simulated Peak (mgd)
Observed Peak (mgd)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA04								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	0.404	0.556	38%	1.126	1.058	-6%	0.915	0.65	-0.265
May 14, 2006									
June 2, 2006	0.328	0.521	59%	0.689	0.865	26%	0.67	0.603	-0.067
June 19, 2006									
June 24, 2006									
June 25, 2006	1.293	1.794	39%	0.776	1.31	69%	1.013	0.72	-0.293
July 5, 2006	1.162	1.212	4%	2.92	1.188	-59%	1.212	0.69	-0.522
July 22, 2006	0.515	0.657	28%	1.065	0.509	-52%	0.76	0.492	-0.268
August 7, 2006	0.664	0.73	10%	0.758	1.074	42%	0.693	0.655	-0.038
September 1, 2006	0.821	0.852	4%	1.063	0.781	-27%	1.236	0.579	-0.657
September 5, 2006									
September 14, 2006	0.723	0.914	26%	0.963	0.589	-39%	1.16	0.514	-0.646
September 28, 2006	0.404	0.644	59%	0.834	0.565	-32%	1.097	0.508	-0.589
October 5, 2006	0.769	0.872	13%	0.992	0.655	-34%	1.033	0.535	-0.498
October 17, 2006	0.493	0.652	32%	0.633	0.527	-17%	1.036	0.497	-0.539
October 19, 2006									
October 27, 2006	0.619	0.802	30%	0.555	0.8	44%	1.409	0.585	-0.824
November 7, 2006	0.592	0.743	26%	0.553	0.612	11%	1.438	0.521	-0.917
November 16, 2006	0.822	0.9	9%	0.804	0.809	1%	0.971	0.587	-0.384
November 22, 2006	0.822	0.9	9%	0.804	0.809	1%	0.971	0.587	-0.384
December 22, 2006	0.696	0.713	2%	0.629	0.506	-20%	0.854	0.491	-0.363
January 1, 2007	0.546	0.535	-2%	0.826	0.691	-16%	0.891	0.548	-0.343
January 7, 2007	0.426	0.404	-5%	0.625	0.49	-22%	0.812	0.486	-0.326
March 1, 2007	0.618	0.697	13%	0.553	0.53	-4%	0.833	0.498	-0.335
March 15, 2007	0.804	0.973	21%	0.77	0.65	-16%	0.97	0.533	-0.437
March 23, 2007									
April 4, 2007	0.493	0.815	65%	0.42	0.553	32%	0.766	0.504	-0.262
April 11, 2007	0.449	0.654	46%	0.569	0.431	-24%	0.836	0.465	-0.371
April 14, 2007	0.822	0.9	9%	0.804	0.809	1%	0.971	0.587	-0.384

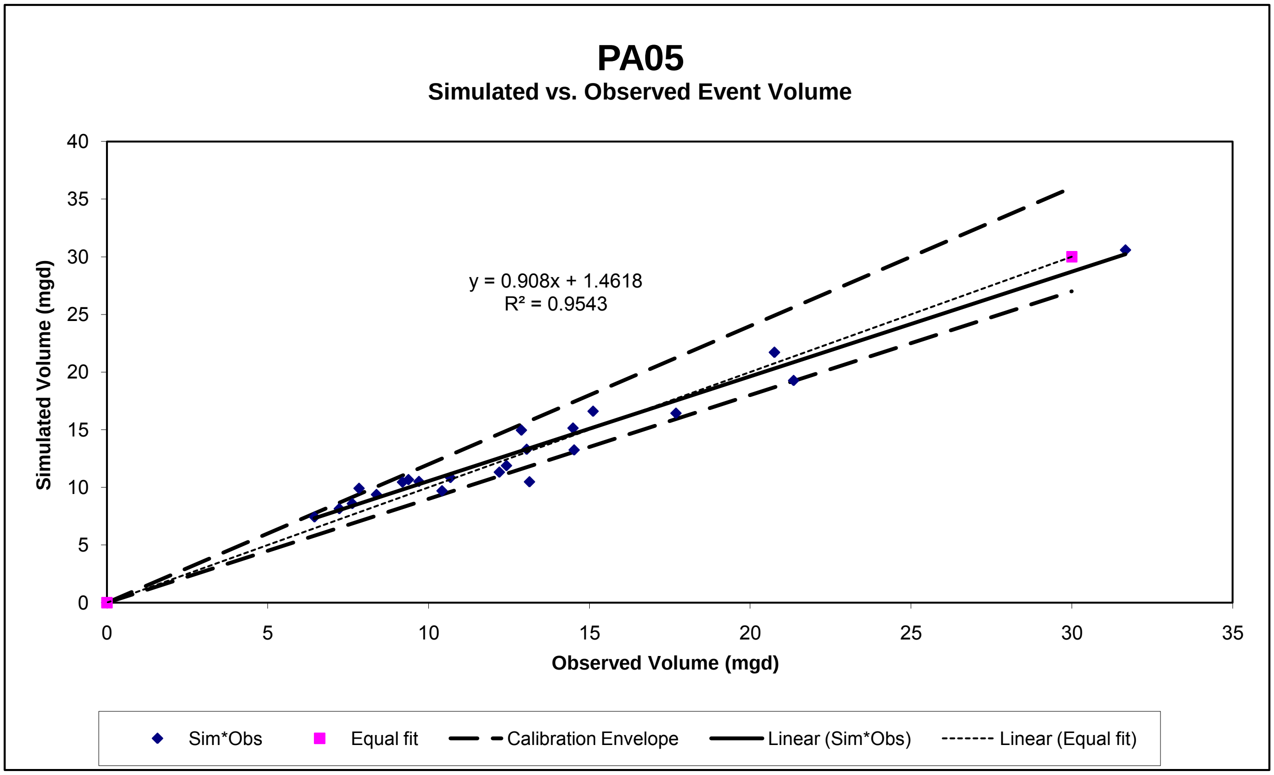


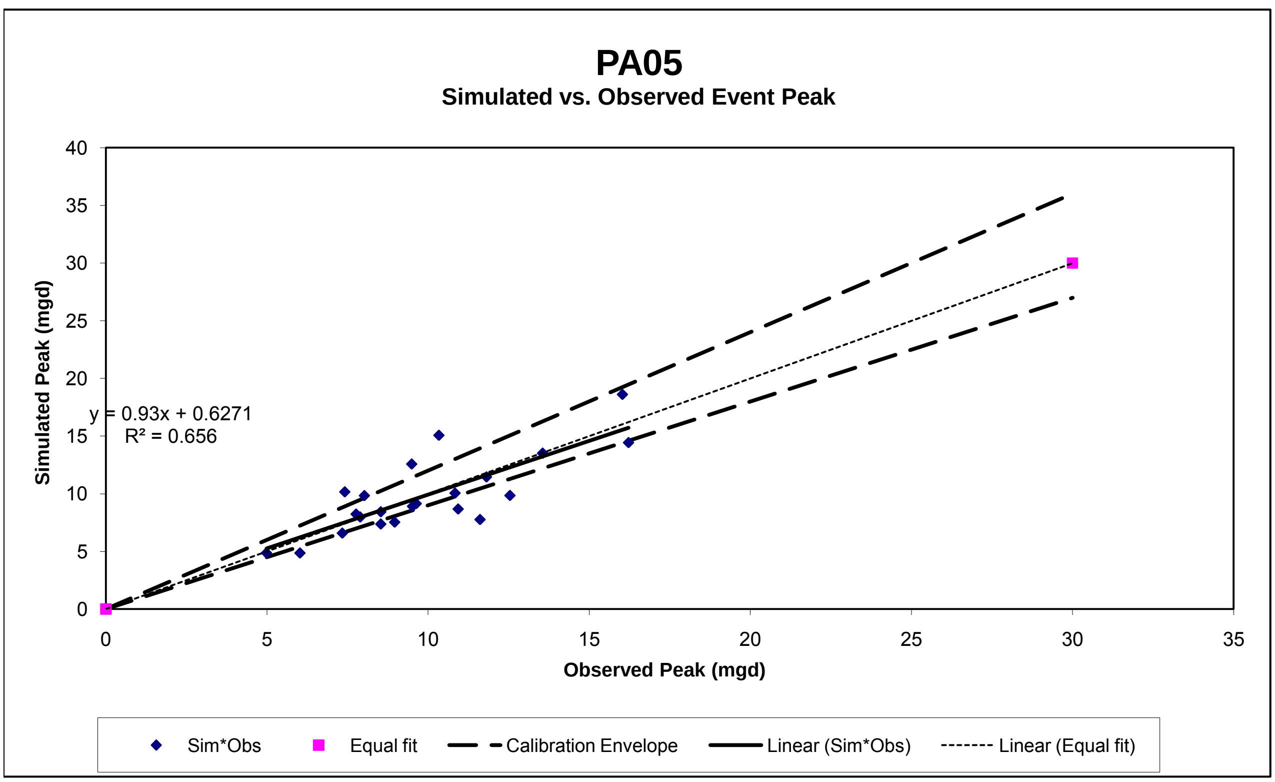
PA04
Simulated vs. Observed Event Volume
y = 1.0778x + 0.0855
R2 = 0.8341
Simulated Volume (mgd)
Observed Volume (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)



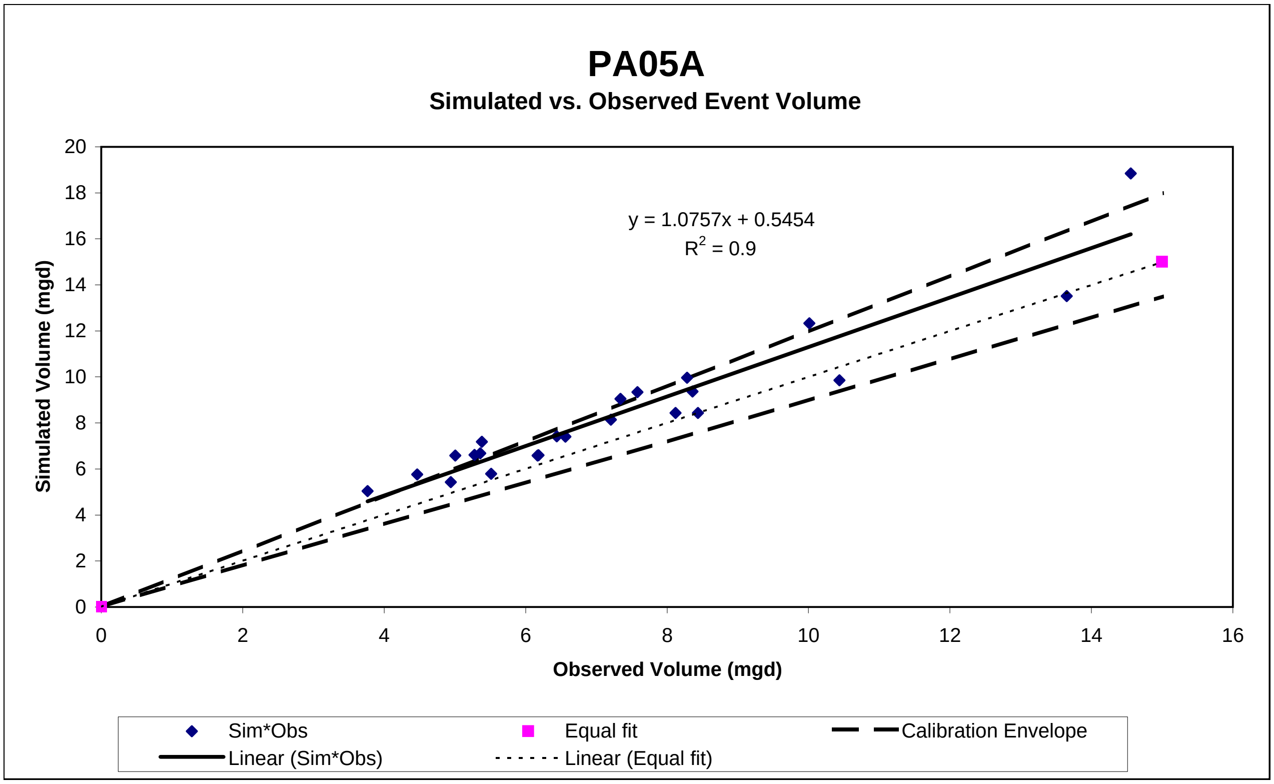
PA04
Simulated vs. Observed Event Peak
y = 0.2417x + 0.5236
R2 = 0.2436
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

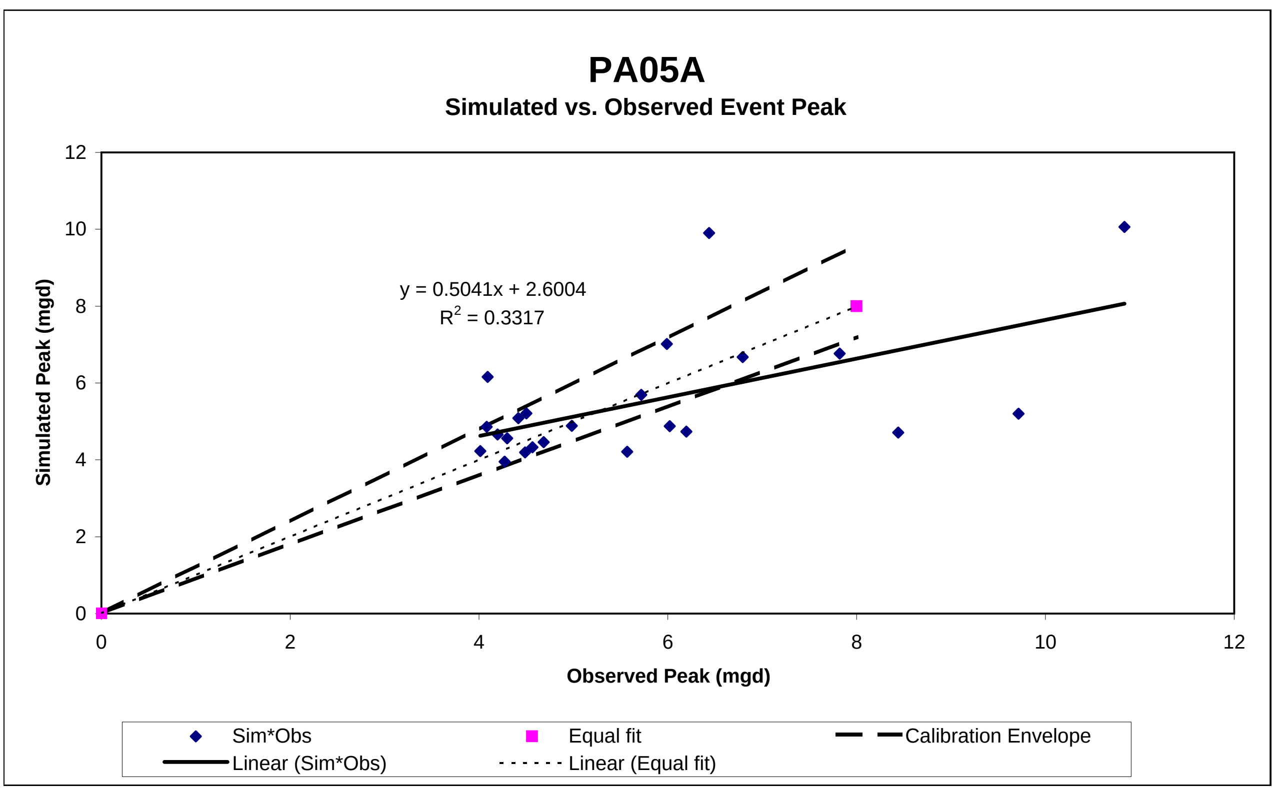
Storm Events	PA05								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	7.837	9.915	27%	10.337	15.08	46%	1.07	1.535	0.465
May 14, 2006									
June 2, 2006	7.627	8.595	13%	9.492	12.589	33%	1.012	1.403	0.391
June 19, 2006									
June 24, 2006									
June 25, 2006	31.666	30.586	-3%	16.035	18.624	16%	1.255	1.707	0.452
July 5, 2006	21.348	19.267	-10%	16.224	14.448	-11%	1.18	1.503	0.323
July 22, 2006	12.199	11.319	-7%	10.935	8.691	-21%	0.988	1.171	0.183
August 7, 2006	10.679	10.849	2%	7.415	10.178	37%	0.843	1.264	0.421
September 1, 2006	15.113	16.6	10%	11.814	11.471	-3%	0.922	1.341	0.419
September 5, 2006									
September 14, 2006	14.489	15.142	5%	9.516	8.925	-6%	0.858	1.186	0.328
September 28, 2006	9.699	10.51	8%	8.533	8.45	-1%	0.88	1.155	0.275
October 5, 2006	12.885	14.959	16%	8.023	9.854	23%	0.915	1.244	0.329
October 17, 2006	9.373	10.669	14%	7.766	8.25	6%	0.801	1.142	0.341
October 19, 2006									
October 27, 2006	7.223	8.15	13%	6.022	4.876	-19%	1.55	1.525	-0.025
November 7, 2006	6.452	7.435	15%	4.983	4.885	-2%	1.416	1.526	0.110
November 16, 2006	8.379	9.377	12%	10.838	10.069	-7%	2.036	2.272	0.236
November 22, 2006	13.136	10.483	-20%	11.614	7.779	-33%	1.042	1.11	0.068
December 22, 2006	12.421	11.886	-4%	8.963	7.552	-16%	0.956	1.094	0.138
January 1, 2007	10.417	9.7	-7%	9.633	9.16	-5%	0.975	1.201	0.226
January 7, 2007	14.524	13.244	-9%	8.533	7.387	-13%	1.008	1.083	0.075
March 1, 2007	13.049	13.3	2%	7.893	7.995	1%	0.935	1.124	0.189
March 15, 2007	17.691	16.429	-7%	12.543	9.865	-21%	1.121	1.245	0.124
March 23, 2007									
April 4, 2007	20.751	21.71	5%	13.558	13.525	0%	1.168	1.454	0.286
April 11, 2007	9.188	10.458	14%	7.338	6.6	-10%	0.953	1.026	0.073
April 14, 2007	20.751	21.71	5%	13.558	13.525	0%	1.168	1.454	0.286


PA05
Simulated vs. Observed Event Volume
y = 0.908x + 1.4618
R² = 0.9543
Simulated Volume (mgd)
Observed Volume (mgd)
0
5
10
15
20
25
30
35
40
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

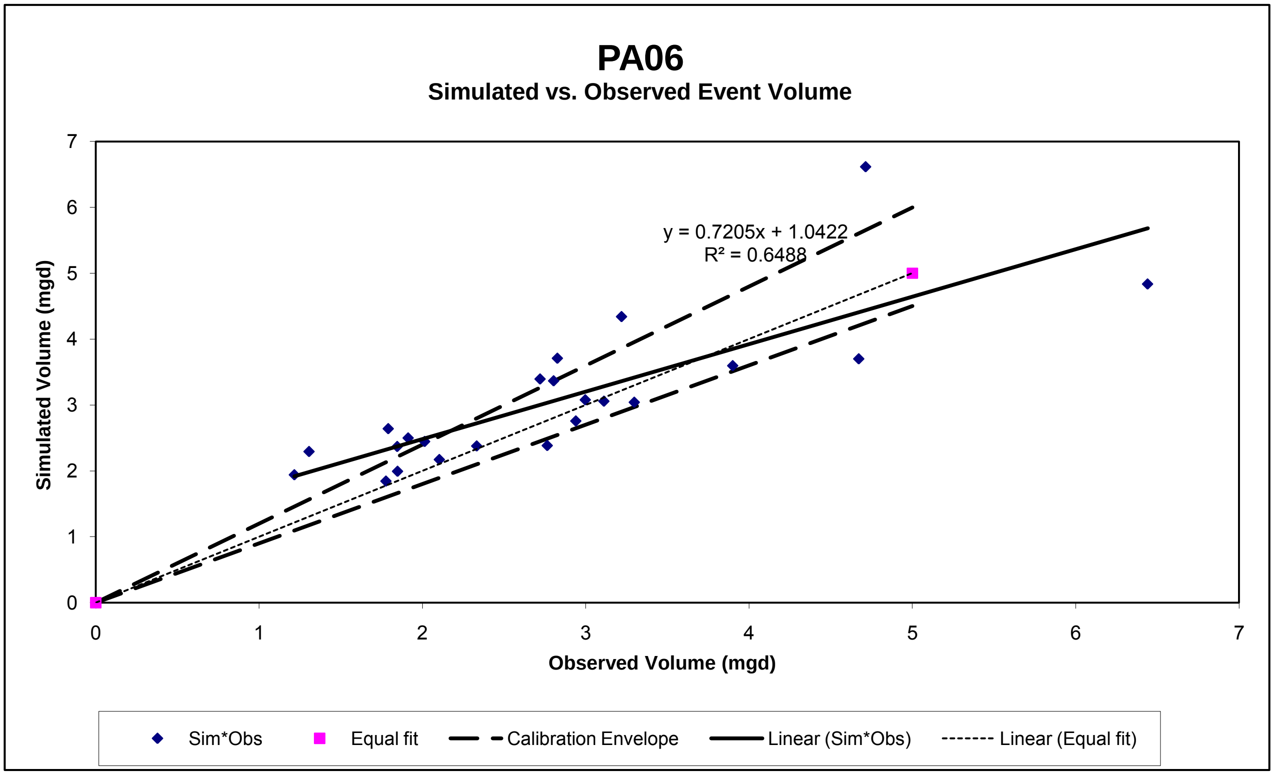

PA05
Simulated vs. Observed Event Peak
y = 0.93x + 0.6271
R² = 0.656
Simulated Peak (mgd)
Observed Peak (mgd)
0
5
10
15
20
25
30
35
40
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

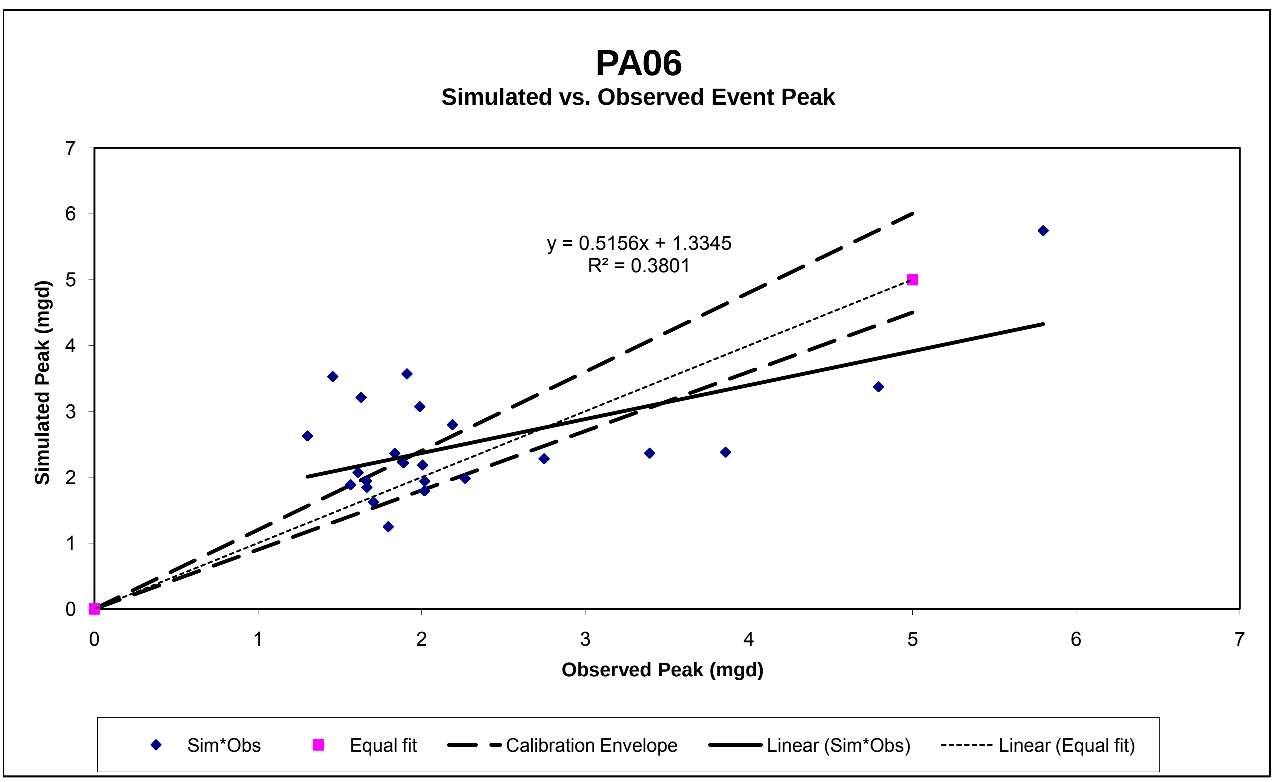
Storm Events	PA05A								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	4.468	5.761	29%	5.989	7.019	17%	1.519	1.856	0.337
May 14, 2006									
June 2, 2006	3.767	5.043	34%	4.091	6.159	51%	1.334	1.717	0.383
June 19, 2006									
June 24, 2006									
June 25, 2006	14.555	18.851	30%	6.438	9.9	54%	1.595	2.247	0.652
July 5, 2006	10.012	12.338	23%	6.792	6.672	-2%	1.609	1.804	0.195
July 22, 2006	5.38	7.179	33%	4.501	5.206	16%	1.389	1.582	0.193
August 7, 2006	5.004	6.589	32%	4.08	4.862	19%	1.301	1.104	-0.197
September 1, 2006	8.284	9.962	20%	5.72	5.69	-1%	1.447	1.66	0.213
September 5, 2006									
September 14, 2006	7.583	9.337	23%	4.195	4.663	11%	1.356	1.495	0.139
September 28, 2006	5.279	6.617	25%	8.44	4.714	-44%	1.8	1.501	-0.299
October 5, 2006	7.341	9.053	23%	4.418	5.082	15%	1.364	1.56	0.196
October 17, 2006	5.358	6.68	25%	4.297	4.562	6%	1.361	1.482	0.121
October 19, 2006									
October 27, 2006	7.207	8.142	13%	6.022	4.873	-19%	1.55	1.524	-0.026
November 7, 2006	6.44	7.425	15%	4.983	4.885	-2%	1.416	1.526	0.110
November 16, 2006	8.359	9.362	12%	10.838	10.062	-7%	2.036	2.271	0.235
November 22, 2006	6.185	6.591	7%	4.565	4.331	-5%	1.336	1.453	0.117
December 22, 2006	6.562	7.404	13%	4.487	4.196	-6%	1.286	1.432	0.146
January 1, 2007	5.511	5.79	5%	6.196	4.734	-24%	1.364	1.504	0.140
January 7, 2007	8.121	8.431	4%	5.568	4.209	-24%	1.325	1.434	0.109
March 1, 2007	8.437	8.44	0%	4.684	4.46	-5%	1.41	1.47	0.060
March 15, 2007	10.436	9.857	-6%	9.714	5.198	-46%	1.777	1.581	-0.196
March 23, 2007									
April 4, 2007	4.942	5.432	10%	4.012	4.228	5%	1.245	1.447	0.202
April 11, 2007	6.171	6.587	7%	4.272	3.951	-8%	1.261	1.387	0.126
April 14, 2007	13.649	13.516	-1%	7.822	6.763	-14%	1.582	1.82	0.238


PA05A
Simulated vs. Observed Event Volume
y = 1.0757x + 0.5454
R^2 = 0.9
Simulated Volume (mgd)
Observed Volume (mgd)
0
2
4
6
8
10
12
14
16
18
20
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

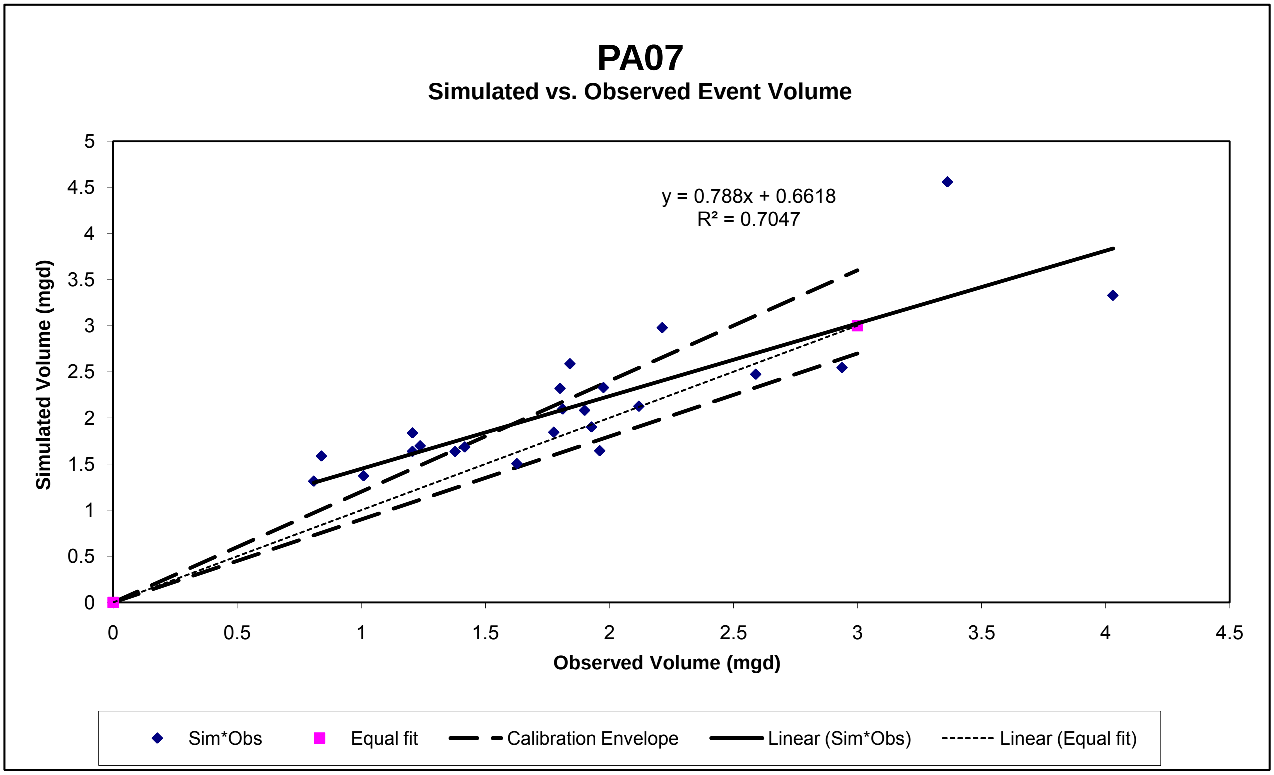

PA05A
Simulated vs. Observed Event Peak
y = 0.5041x + 2.6004
R^2 = 0.3317
Simulated Peak (mgd)
Observed Peak (mgd)
0
2
4
6
8
10
12
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

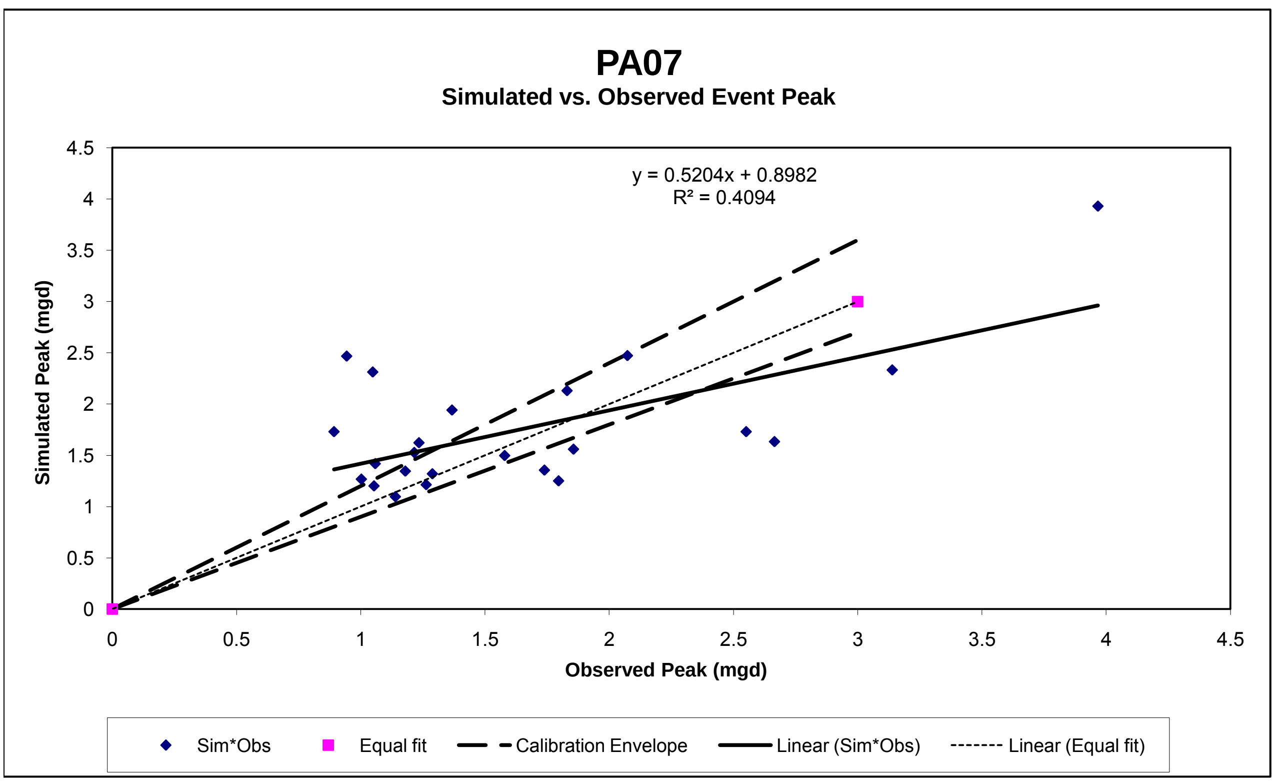
Storm Events	PA06								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	1.305	2.294	76%	1.456	3.53	142%	0.756	1.3	0.544
May 14, 2006									
June 2, 2006	1.215	1.941	60%	1.302	2.626	102%	0.71	1.118	0.408
June 19, 2006									
June 24, 2006									
June 25, 2006	4.714	6.617	40%	1.91	3.57	87%	0.869	1.309	0.440
July 5, 2006	3.219	4.342	35%	1.988	3.073	55%	0.867	1.212	0.345
July 22, 2006	1.912	2.5	31%	1.665	1.849	11%	1.239	0.952	-0.287
August 7, 2006	1.79	2.641	48%	1.63	3.213	97%	0.747	1.239	0.492
September 1, 2006	2.826	3.71	31%	2.188	2.799	28%	0.813	1.154	0.341
September 5, 2006									
September 14, 2006	2.803	3.367	20%	1.889	2.219	17%	0.79	1.032	0.242
September 28, 2006	1.845	2.37	28%	1.611	2.071	29%	0.749	0.999	0.250
October 5, 2006	2.72	3.395	25%	1.835	2.364	29%	0.757	1.066	0.309
October 17, 2006	2.013	2.446	22%	1.662	1.945	17%	0.742	0.973	0.231
October 19, 2006									
October 27, 2006	2.997	3.079	3%	3.393	2.365	-30%	1.087	1.066	-0.021
November 7, 2006	2.939	2.758	-6%	2.748	2.281	-17%	0.926	1.047	0.121
November 16, 2006	3.9	3.597	-8%	5.799	5.746	-1%	1.563	1.763	0.200
November 22, 2006	2.764	2.385	-14%	2.266	1.983	-12%	0.837	0.981	0.144
December 22, 2006	1.776	1.845	4%	1.796	1.251	-30%	0.547	0.506	-0.041
January 1, 2007	2.103	2.172	3%	2.006	2.186	9%	0.829	1.025	0.196
January 7, 2007	3.297	3.042	-8%	2.017	1.794	-11%	0.783	0.939	0.156
March 1, 2007	3.111	3.058	-2%	2.019	1.942	-4%	0.894	0.972	0.078
March 15, 2007	4.672	3.701	-21%	3.857	2.38	-38%	1.219	1.069	-0.150
March 23, 2007									
April 4, 2007	1.847	1.994	8%	1.566	1.887	20%	0.762	0.96	0.198
April 11, 2007	2.332	2.378	2%	1.705	1.623	-5%	0.768	0.896	0.128
April 14, 2007	6.441	4.837	-25%	4.792	3.376	-30%	1.296	1.269	-0.027


PA06
Simulated vs. Observed Event Volume
y = 0.7205x + 1.0422
R² = 0.6488
Simulated Volume (mgd)
Observed Volume (mgd)
0
1
2
3
4
5
6
7
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

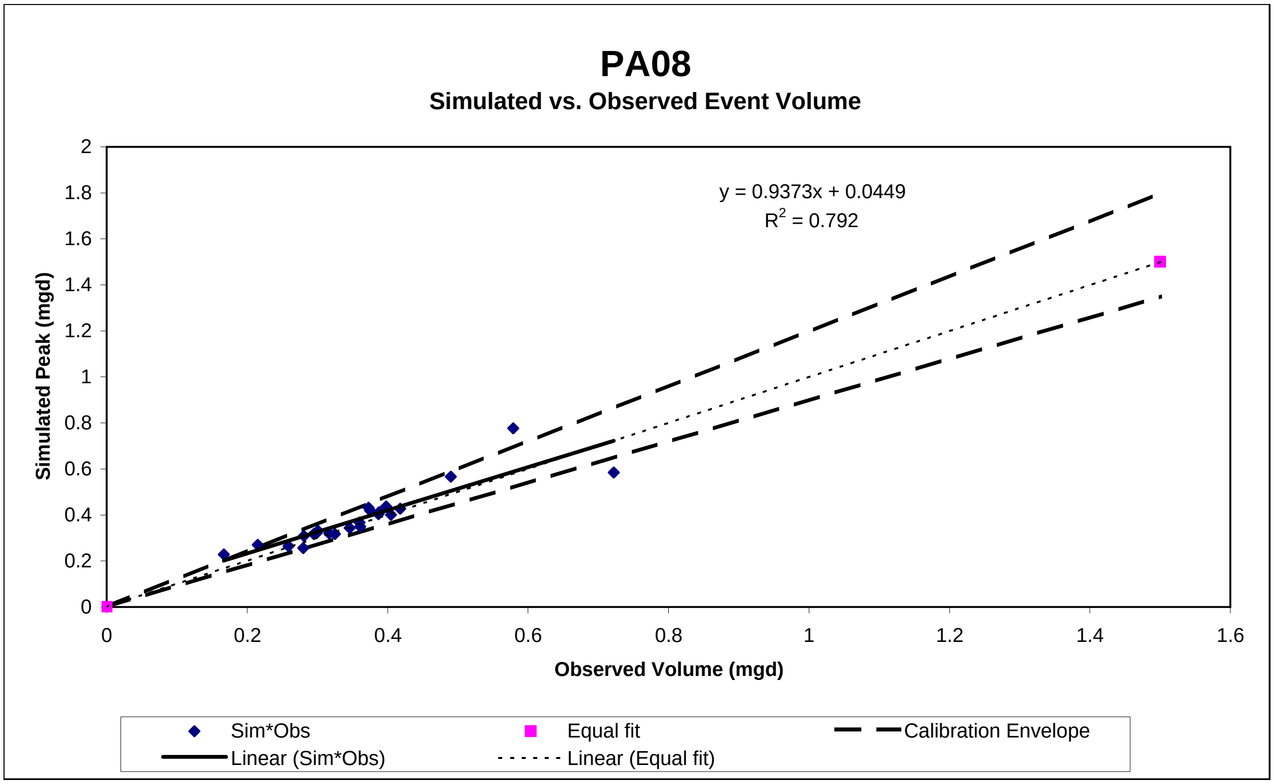

PA06
Simulated vs. Observed Event Peak
y = 0.5156x + 1.3345
R² = 0.3801
Simulated Peak (mgd)
Observed Peak (mgd)
0
1
2
3
4
5
6
7
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA07								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	0.839	1.586	89%	0.943	2.468	162%	0.4	0.716	0.316
May 14, 2006									
June 2, 2006	0.808	1.314	63%	0.892	1.731	94%	0.402	0.597	0.195
June 19, 2006									
June 24, 2006									
June 25, 2006	3.363	4.559	36%	2.073	2.473	19%	0.618	0.717	0.099
July 5, 2006	2.213	2.978	35%	1.83	2.131	16%	0.574	0.664	0.090
July 22, 2006	1.237	1.697	37%	1.053	1.202	14%	0.435	0.496	0.061
August 7, 2006	1.206	1.837	52%	1.048	2.313	121%	0.414	0.693	0.279
September 1, 2006	1.841	2.587	41%	1.367	1.942	42%	0.485	0.633	0.148
September 5, 2006									
September 14, 2006	1.801	2.321	29%	1.215	1.528	26%	0.454	0.56	0.106
September 28, 2006	1.206	1.637	36%	1.058	1.419	34%	0.42	0.539	0.119
October 5, 2006	1.976	2.329	18%	1.234	1.623	32%	0.465	0.578	0.113
October 17, 2006	1.417	1.685	19%	1.179	1.346	14%	0.452	0.525	0.073
October 19, 2006									
October 27, 2006	2.119	2.127	0%	2.551	1.731	-32%	0.679	0.597	-0.082
November 7, 2006	1.928	1.901	-1%	1.856	1.56	-16%	0.569	0.566	-0.003
November 16, 2006	2.59	2.473	-5%	3.967	3.931	-1%	0.868	0.912	0.044
November 22, 2006	1.961	1.644	-16%	1.739	1.356	-22%	0.55	0.527	-0.023
December 22, 2006	1.776	1.845	4%	1.796	1.251	-30%	0.547	0.506	-0.041
January 1, 2007	1.627	1.504	-8%	1.579	1.498	-5%	0.508	0.555	0.047
January 7, 2007	1.9	2.082	10%	1.263	1.214	-4%	0.489	0.499	0.010
March 1, 2007	1.812	2.096	16%	1.288	1.32	2%	0.477	0.52	0.043
March 15, 2007	2.938	2.545	-13%	2.665	1.634	-39%	0.714	0.58	-0.134
March 23, 2007									
April 4, 2007	1.009	1.372	36%	1.002	1.268	27%	0.45	0.51	0.060
April 11, 2007	1.378	1.636	19%	1.139	1.097	-4%	0.528	0.474	-0.054
April 14, 2007	4.03	3.329	-17%	3.139	2.333	-26%	0.73	0.696	-0.034

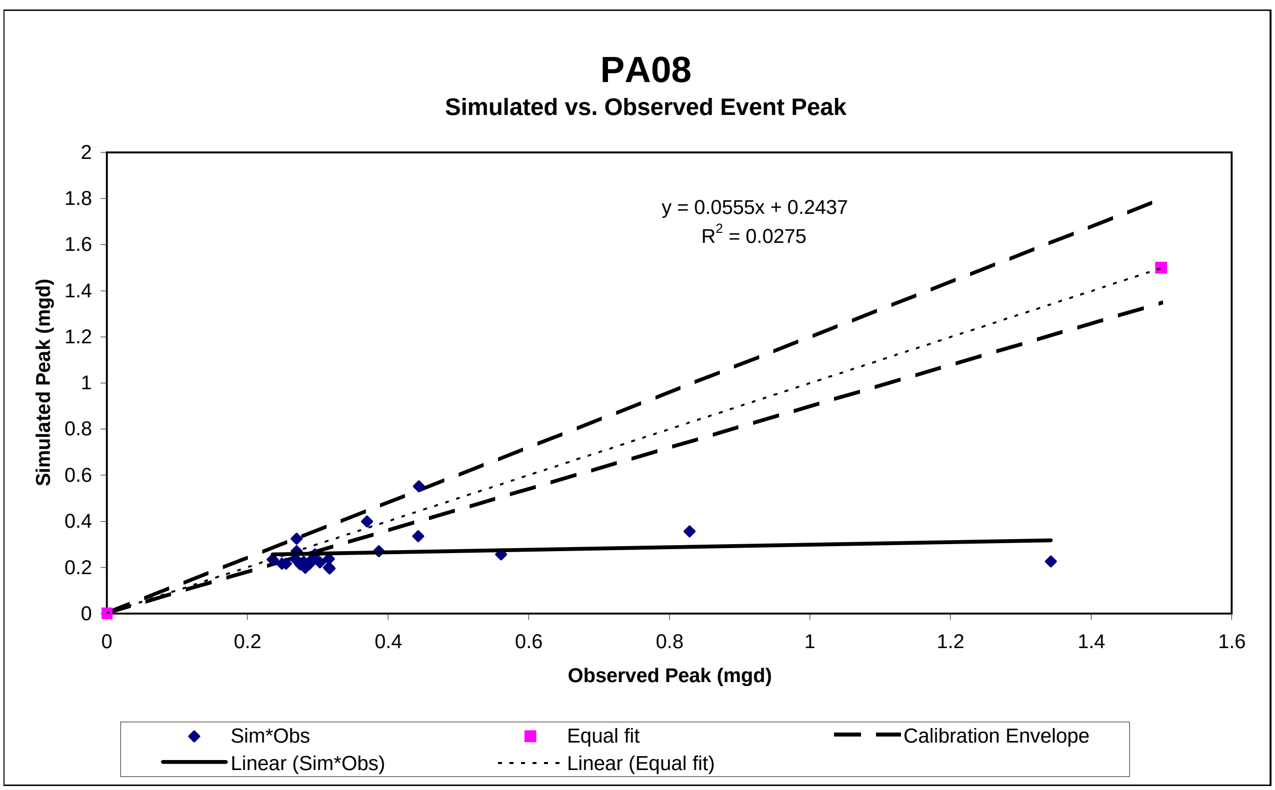

PA07
Simulated vs. Observed Event Volume
y = 0.788x + 0.6618
R² = 0.7047
Simulated Volume (mgd)
Observed Volume (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)


PA07
Simulated vs. Observed Event Peak
y = 0.5204x + 0.8982
R² = 0.4094
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA08								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	0.28	0.256	-9%	0.829	0.357	-57%	0.377	0.25	-0.127
May 14, 2006									
June 2, 2006	0.167	0.228	37%	0.27	0.324	20%	0.175	0.239	0.064
June 19, 2006									
June 24, 2006									
June 25, 2006	0.579	0.776	34%	0.37	0.399	8%	0.217	0.264	0.047
July 5, 2006	0.49	0.566	16%	0.443	0.336	-24%	0.242	0.243	0.001
July 22, 2006	0.301	0.331	10%	0.561	0.257	-54%	0.24	0.217	-0.023
August 7, 2006	0.299	0.321	7%	0.27	0.271	0%	0.225	0.221	-0.004
September 1, 2006	0.418	0.427	2%	0.296	0.257	-13%	0.223	0.217	-0.006
September 5, 2006									
September 14, 2006	0.373	0.432	16%	0.268	0.237	-12%	0.223	0.212	-0.011
September 28, 2006	0.281	0.309	10%	0.293	0.239	-18%	0.227	0.212	-0.015
October 5, 2006	0.388	0.412	6%	0.28	0.224	-20%	0.218	0.208	-0.010
October 17, 2006	0.295	0.317	7%	0.249	0.216	-13%	0.208	0.205	-0.003
October 19, 2006									
October 27, 2006	0.36	0.367	2%	1.343	0.226	-83%	2.603	0.208	-2.395
November 7, 2006	0.346	0.344	-1%	0.275	0.213	-23%	0.236	0.204	-0.032
November 16, 2006	0.375	0.419	12%	0.444	0.552	24%	0.239	0.301	0.062
November 22, 2006	0.325	0.317	-2%	0.303	0.222	-27%	0.251	0.207	-0.044
December 22, 2006	0.361	0.349	-3%	0.255	0.216	-15%	0.086	0.101	0.015
January 1, 2007	0.215	0.27	26%	0.236	0.235	0%	0.213	0.211	-0.002
January 7, 2007	0.387	0.404	4%	0.282	0.199	-29%	0.215	0.199	-0.016
March 1, 2007	0.405	0.401	-1%	0.316	0.2	-37%	0.277	0.2	-0.077
March 15, 2007	0.398	0.437	10%	0.316	0.237	-25%	0.244	0.211	-0.033
March 23, 2007									
April 4, 2007	0.259	0.264	2%	0.288	0.215	-25%	0.235	0.205	-0.030
April 11, 2007	0.317	0.32	1%	0.317	0.196	-38%	0.238	0.198	-0.040
April 14, 2007	0.722	0.584	-19%	0.387	0.27	-30%	0.257	0.221	-0.036

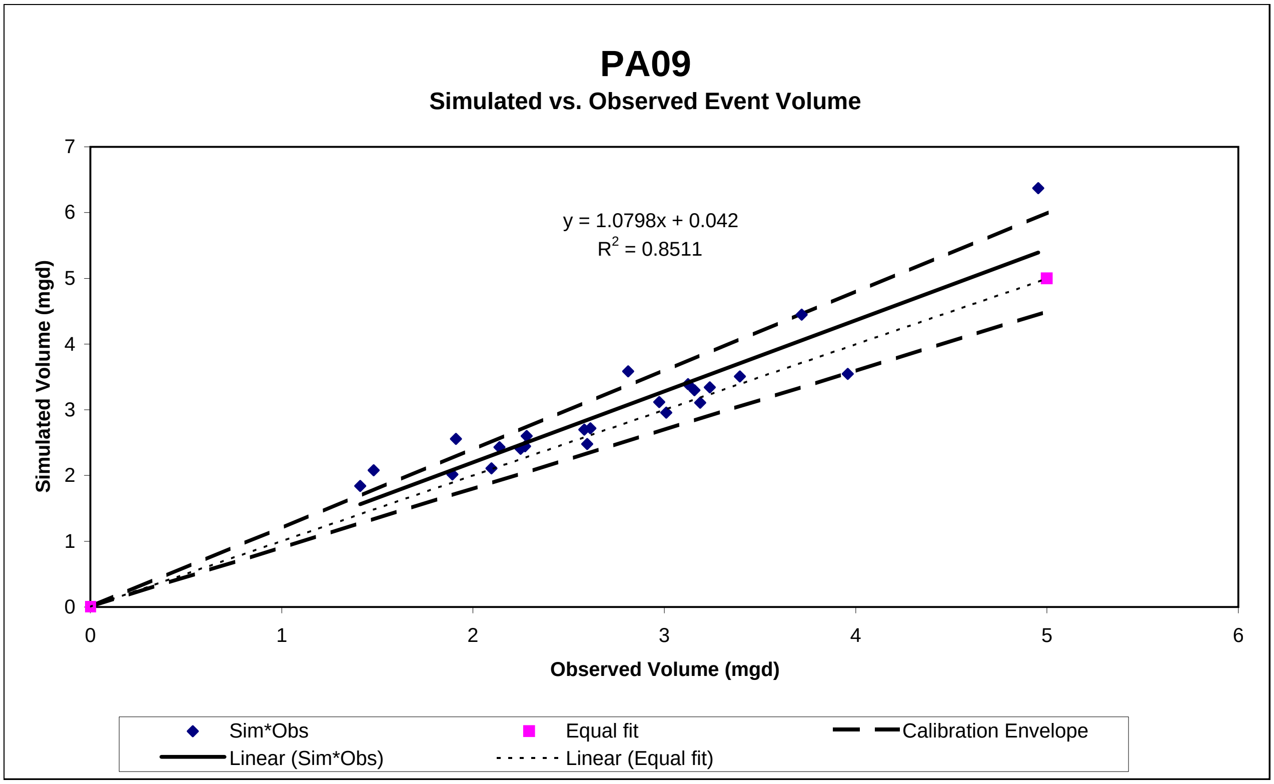


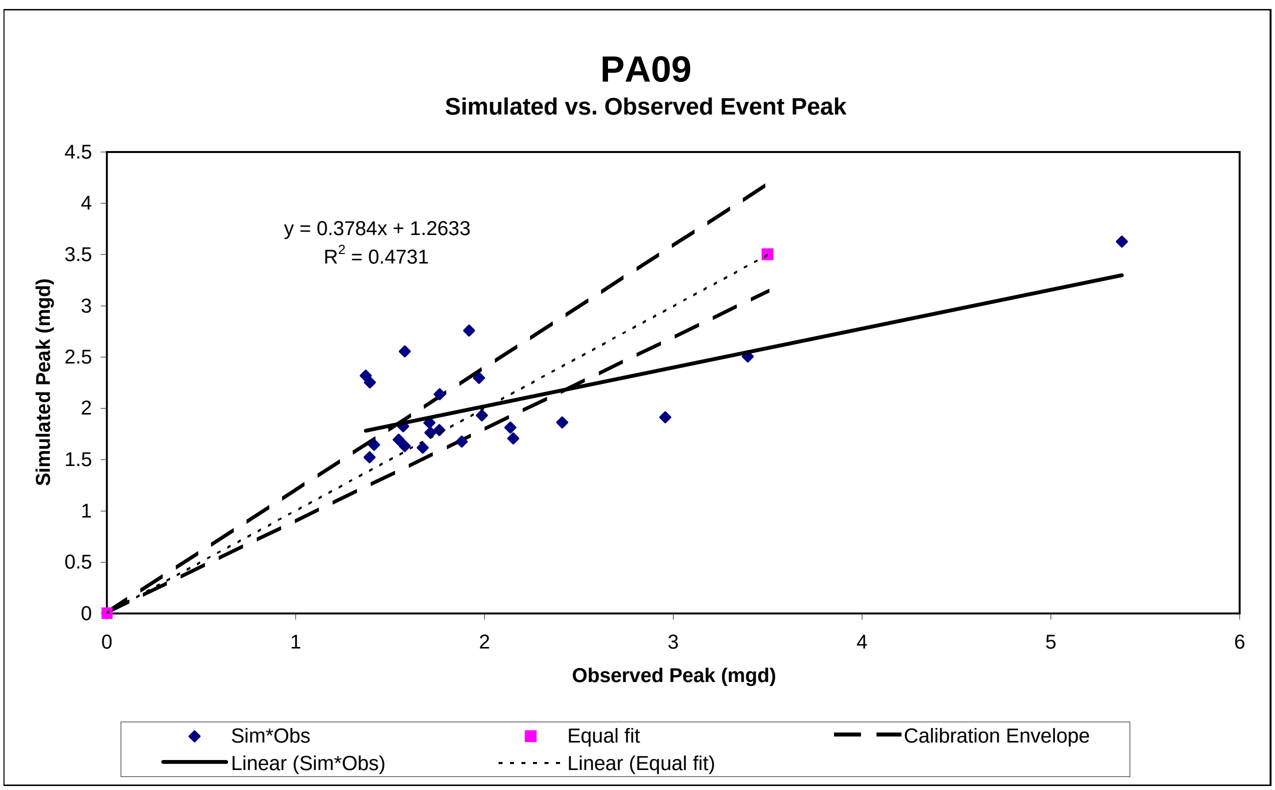
PA08
Simulated vs. Observed Event Volume
y = 0.9373x + 0.0449
R^2 = 0.792
Simulated Peak (mgd)
Observed Volume (mgd)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)



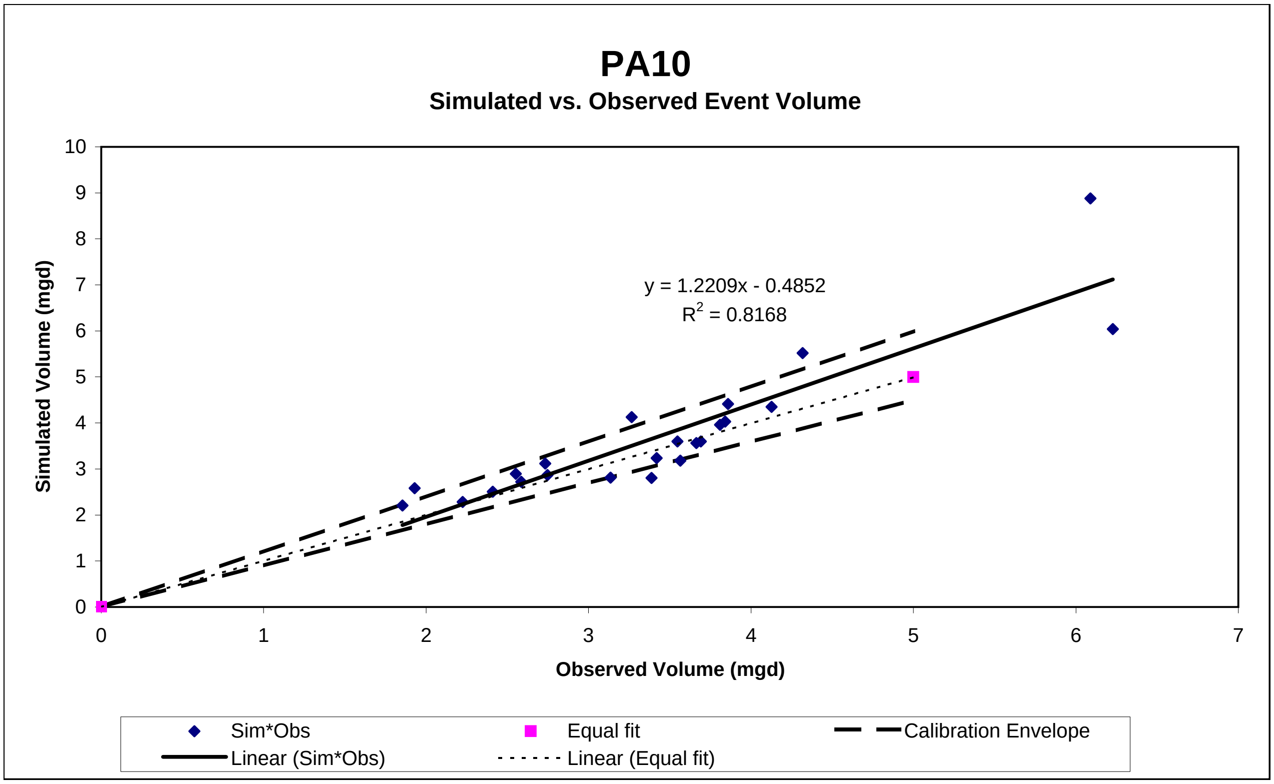
PA08
Simulated vs. Observed Event Peak
y = 0.0555x + 0.2437
R^2 = 0.0275
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA09								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	1.48	2.08	41%	1.578	2.555	62%	0.611	0.753	0.142
May 14, 2006									
June 2, 2006	1.41	1.839	30%	1.393	2.253	62%	0.600	0.716	0.116
June 19, 2006									
June 24, 2006									
June 25, 2006	4.955	6.37	29%	1.918	2.758	44%	0.769	0.791	0.022
July 5, 2006	3.718	4.447	20%	1.972	2.298	17%	0.763	0.722	-0.041
July 22, 2006	2.281	2.599	14%	1.569	1.825	16%	0.633	0.643	0.010
August 7, 2006	1.911	2.557	34%	1.372	2.32	69%	0.566	0.725	0.159
September 1, 2006	2.811	3.586	28%	1.763	2.139	21%	0.657	0.699	0.042
September 5, 2006									
September 14, 2006	3.123	3.392	9%	1.713	1.763	3%	0.617	0.630	0.013
September 28, 2006	2.249	2.405	7%	1.761	1.789	2%	0.606	0.636	0.030
October 5, 2006	3.158	3.299	4%	1.986	1.933	-3%	0.620	0.664	0.044
October 17, 2006	2.272	2.445	8%	1.88	1.675	-11%	0.609	0.613	0.004
October 19, 2006									
October 27, 2006	3.01	2.956	-2%	2.412	1.864	-23%	0.736	0.648	-0.088
November 7, 2006	2.581	2.699	5%	1.709	1.860	9%	0.628	0.650	0.022
November 16, 2006	3.237	3.344	3%	5.377	3.626	-33%	1.108	0.871	-0.237
November 22, 2006	2.597	2.479	-5%	2.152	1.707	-21%	0.636	0.619	-0.017
December 22, 2006	2.613	2.716	4%	1.578	1.631	3%	0.557	0.605	0.048
January 1, 2007	2.097	2.11	1%	2.138	1.813	-15%	0.655	0.64	-0.015
January 7, 2007	3.188	3.11	-2%	1.673	1.616	-3%	0.568	0.603	0.035
March 1, 2007	2.973	3.12	5%	1.546	1.694	10%	0.577	0.617	0.040
March 15, 2007	3.959	3.544	-10%	2.958	1.914	-35%	0.804	0.660	-0.144
March 23, 2007									
April 4, 2007	1.893	2.015	6%	1.416	1.646	16%	0.569	0.608	0.039
April 11, 2007	2.138	2.43	14%	1.391	1.523	9%	0.556	0.586	0.030
April 14, 2007	3.395	3.506	3%	3.395	2.506	-26%	0.85	0.751	-0.099

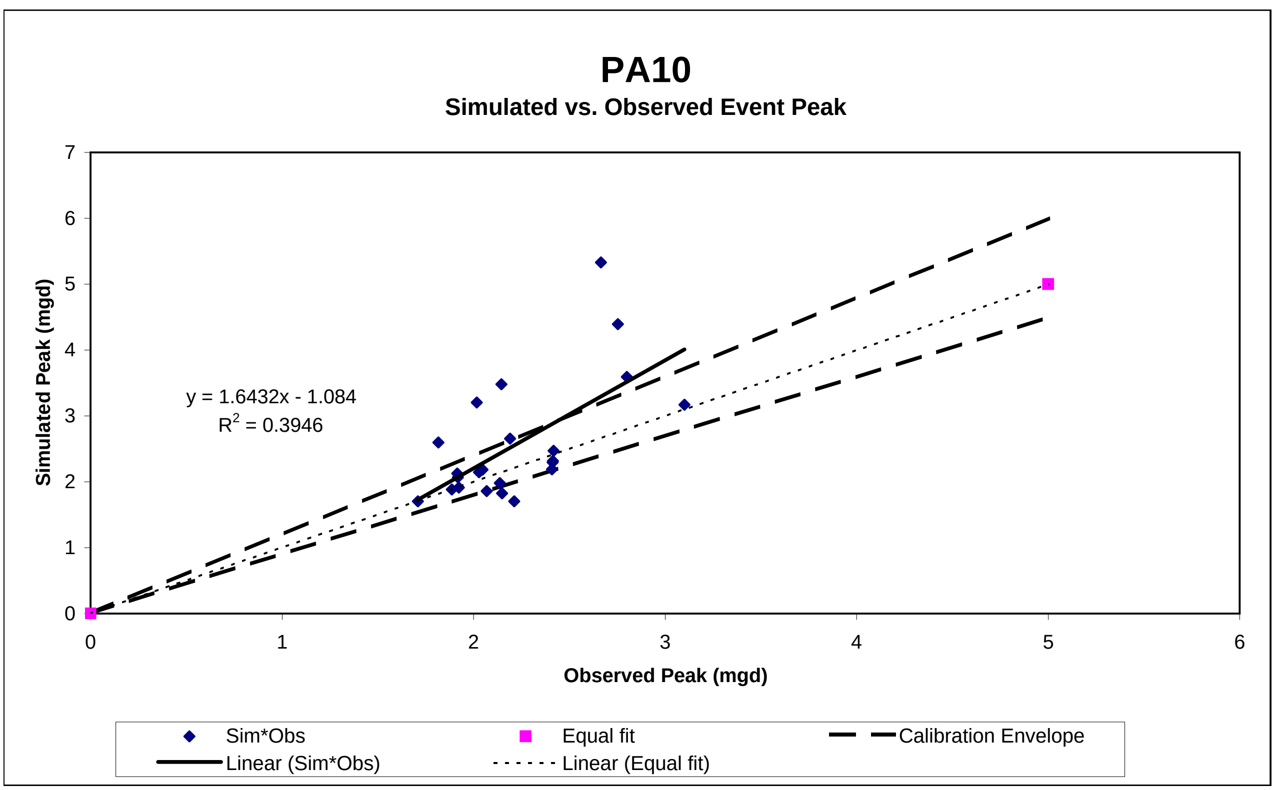

PA09
Simulated vs. Observed Event Volume
y = 1.0798x + 0.042
R2 = 0.8511
Simulated Volume (mgd)
Observed Volume (mgd)
0
1
2
3
4
5
6
7
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)


PA09
Simulated vs. Observed Event Peak
y = 0.3784x + 1.2633
R2 = 0.4731
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
6
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA10								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	1.93	2.581	34%	2.146	3.482	62%	1.413	1.586	0.173
May 14, 2006									
June 2, 2006	1.854	2.207	19%	2.017	3.203	59%	1.366	1.543	0.177
June 19, 2006									
June 24, 2006									
June 25, 2006	6.09	8.879	46%	2.665	5.332	100%	1.596	2.385	0.789
July 5, 2006	4.317	5.515	28%	2.8	3.594	28%	1.647	9.19	7.543
July 22, 2006	2.733	3.116	14%	1.817	2.597	43%	1.354	1.428	0.074
August 7, 2006	2.586	2.719	5%	1.887	1.884	0%	1.357	1.294	-0.063
September 1, 2006	3.859	4.409	14%	2.19	2.654	21%	1.431	1.449	0.018
September 5, 2006									
September 14, 2006	3.841	4.029	5%	1.918	2.07	8%	1.368	1.327	-0.041
September 28, 2006	2.748	2.87	4%	2.046	2.185	7%	1.404	1.341	-0.063
October 5, 2006	3.81	3.96	4%	2.415	2.317	-4%	1.375	1.1372	-0.238
October 17, 2006	2.552	2.897	14%	2.028	2.147	6%	1.371	1.337	-0.034
October 19, 2006									
October 27, 2006	3.664	3.566	-3%	2.412	2.294	-5%	1.544	1.374	-0.170
November 7, 2006	3.420	3.233	-5%	2.41	2.19	-9%	1.495	1.347	-0.148
November 16, 2006	3.265	4.125	26%	2.754	4.395	60%	2.298	1.764	-0.534
November 22, 2006	3.135	2.809	-10%	2.068	1.86	-10%	1.400	1.291	-0.109
December 22, 2006	3.566	3.181	-11%	2.149	1.823	-15%	1.343	1.283	-0.060
January 1, 2007	2.41	2.503	4%	1.914	2.126	11%	1.383	1.333	-0.050
January 7, 2007	3.547	3.6	1%	1.923	1.915	0%	1.385	1.302	-0.083
March 1, 2007	3.692	3.601	-2%	2.137	1.983	-7%	1.357	1.313	-0.044
March 15, 2007	4.126	4.348	5%	2.417	2.471	2%	1.647	1.409	-0.238
March 23, 2007									
April 4, 2007	2.224	2.285	3%	1.71	1.702	0%	1.447	1.256	-0.191
April 11, 2007	3.387	2.801	-17%	2.213	1.704	-23%	1.348	1.257	-0.091
April 14, 2007	6.227	6.039	-3%	3.101	3.17	2%	1.607	1.147	-0.460

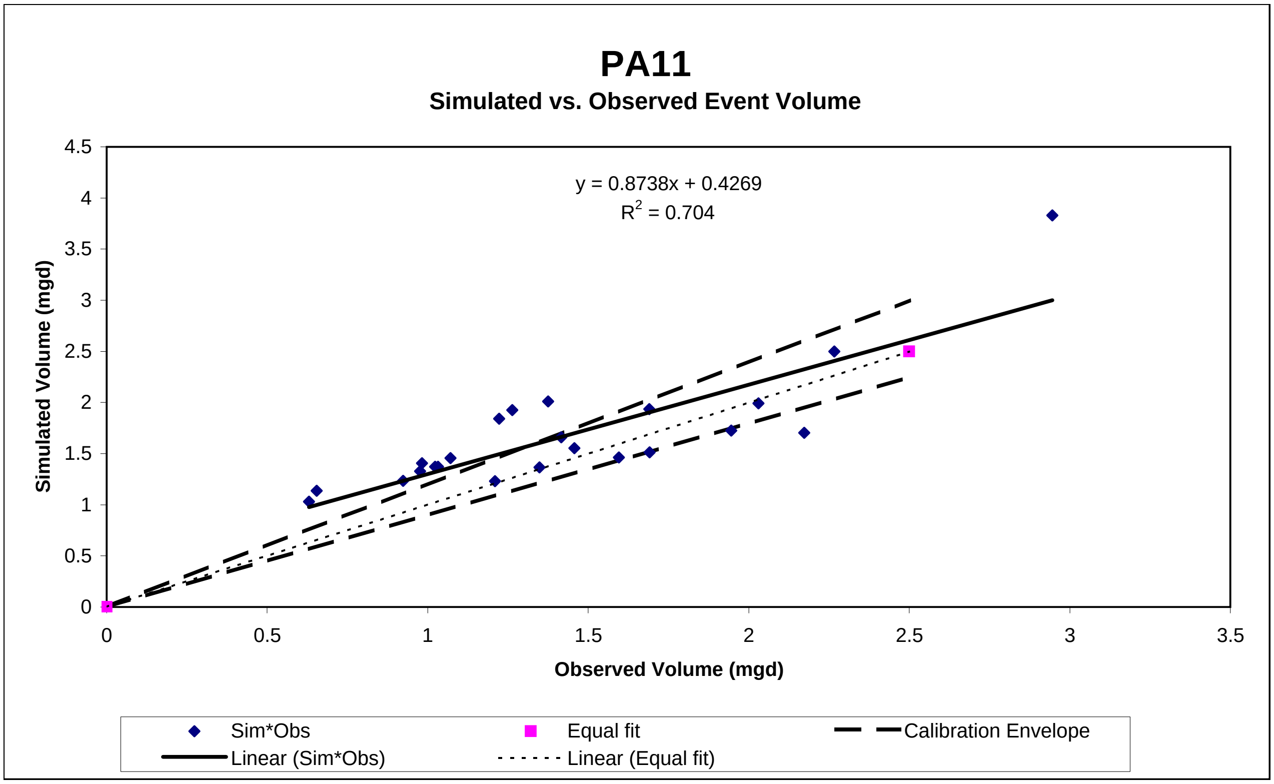


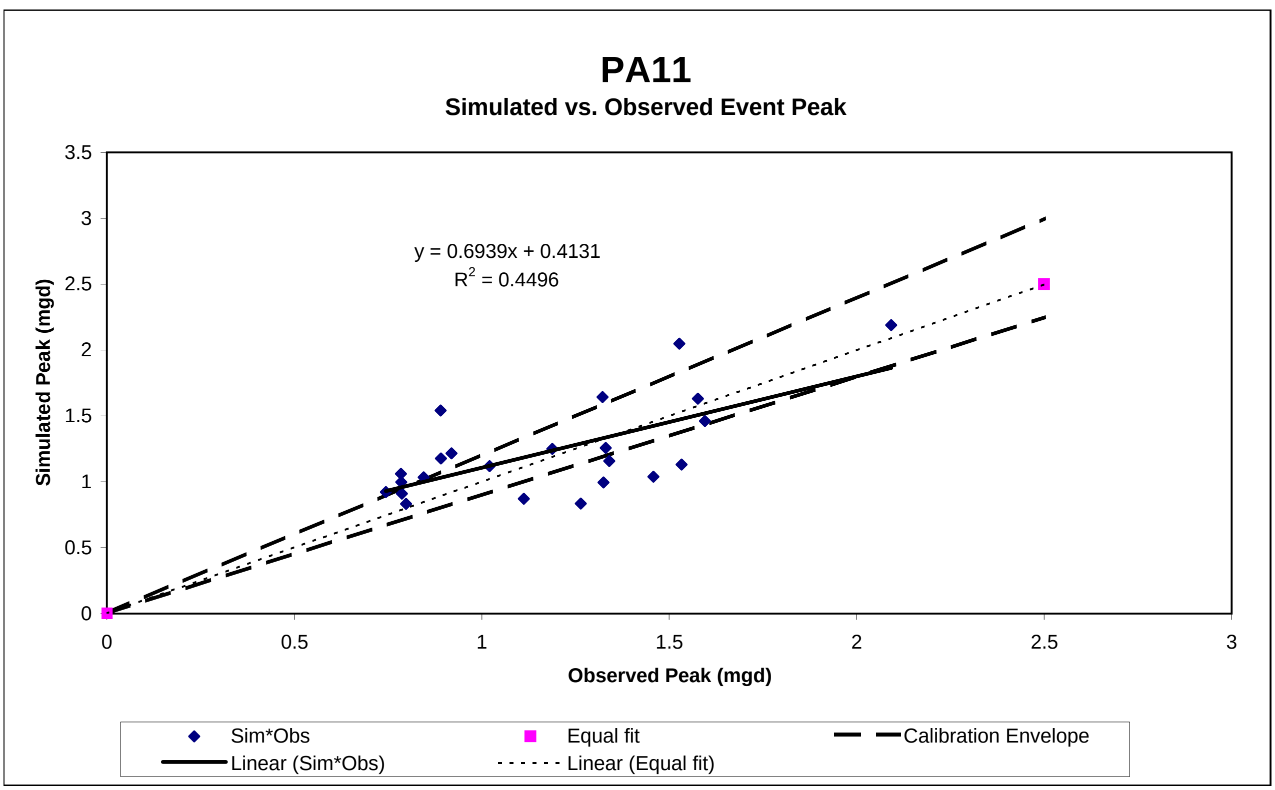
PA10
Simulated vs. Observed Event Volume
y = 1.2209x - 0.4852
R2 = 0.8168
Simulated Volume (mgd)
Observed Volume (mgd)
0
1
2
3
4
5
6
7
8
9
10
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)



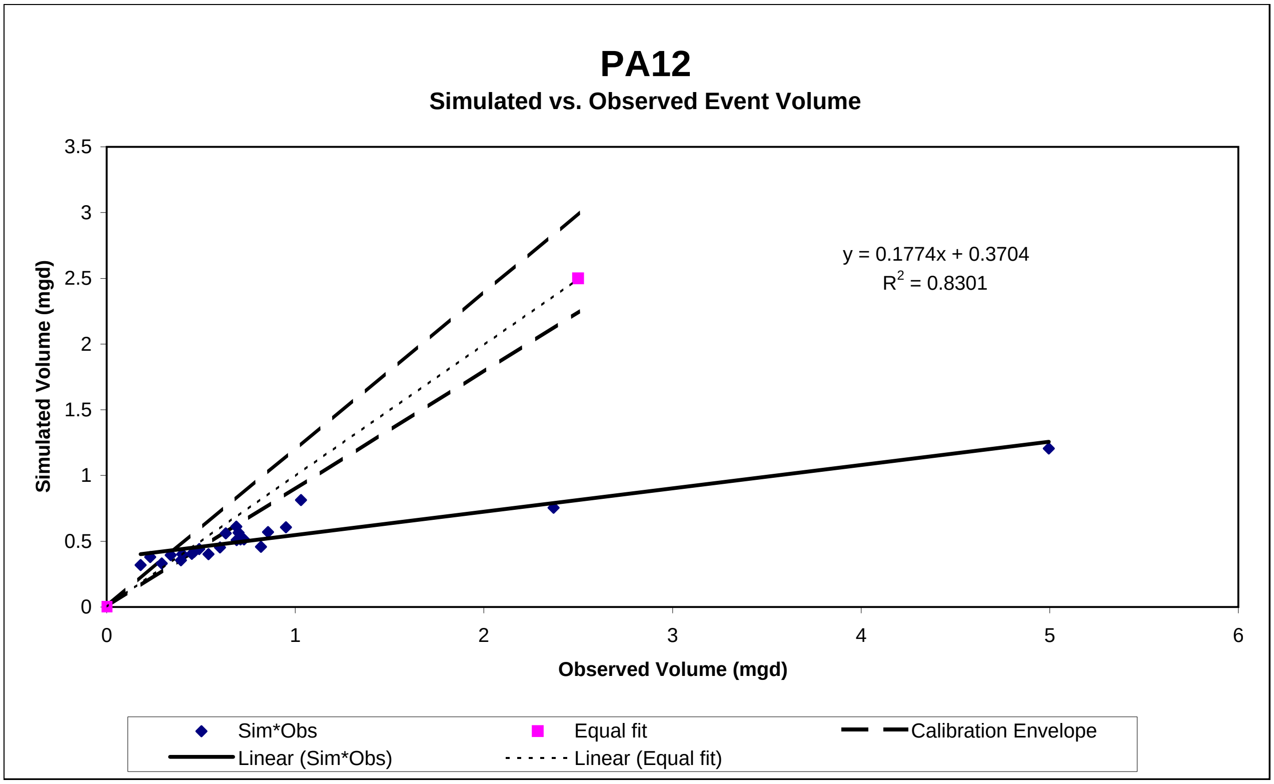
PA10
Simulated vs. Observed Event Peak
y = 1.6432x - 1.084
R2 = 0.3946
Simulated Peak (mgd)
Observed Peak (mgd)
0
1
2
3
4
5
6
7
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA11								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	0.923	1.235	34%	1.322	1.644	24%	1.7	1.711	0.011
May 14, 2006									
June 2, 2006	0.63	1.029	63%	0.89	1.542	73%	1.519	1.607	0.088
June 19, 2006									
June 24, 2006									
June 25, 2006	2.946	3.831	30%	1.527	2.048	34%	1.778	2.23	0.452
July 5, 2006	2.267	2.499	10%	1.576	1.632	4%	2.019	1.687	-0.332
July 22, 2006	1.071	1.457	36%	0.891	1.177	32%	1.489	1.376	-0.113
August 7, 2006	0.976	1.328	36%	0.798	0.832	4%	1.433	1.218	-0.215
September 1, 2006	1.375	2.011	46%	1.188	1.25	5%	1.626	1.425	-0.201
September 5, 2006									
September 14, 2006	1.263	1.927	53%	0.785	0.998	27%	1.5	1.295	-0.205
September 28, 2006	1.032	1.372	33%	0.845	1.034	22%	1.603	1.307	-0.296
October 5, 2006	1.223	1.840	50%	0.919	1.217	32%	1.654	1.398	-0.256
October 17, 2006	0.982	1.406	43%	0.784	1.06	35%	1.542	1.319	-0.223
October 19, 2006									
October 27, 2006	1.416	1.661	17%	1.533	1.13	-26%	1.884	1.352	-0.532
November 7, 2006	1.457	1.553	7%	1.340	1.157	-14%	1.705	1.371	-0.334
November 16, 2006	1.69	1.935	14%	2.092	2.189	5%	2.799	2.391	-0.408
November 22, 2006	1.348	1.366	1%	1.112	0.871	-22%	1.883	1.233	-0.650
December 22, 2006	1.691	1.514	-10%	1.264	0.834	-34%	1.873	1.218	-0.655
January 1, 2007	1.21	1.23	2%	1.021	1.12	10%	1.785	1.351	-0.434
January 7, 2007	1.945	1.725	-11%	1.325	0.996	-25%	1.855	1.293	-0.562
March 1, 2007	2.173	1.702	-22%	1.458	1.04	-29%	1.762	1.312	-0.450
March 15, 2007	2.03	1.991	-2%	1.331	1.258	-5%	2.049	1.419	-0.630
March 23, 2007									
April 4, 2007	0.654	1.138	74%	0.744	0.923	24%	1.658	1.2256	-0.432
April 11, 2007	1.023	1.372	34%	0.787	0.911	16%	1.778	1.251	-0.527
April 14, 2007	1.595	1.461	-8%	1.595	1.461	-8%	1.788	1.57	-0.218

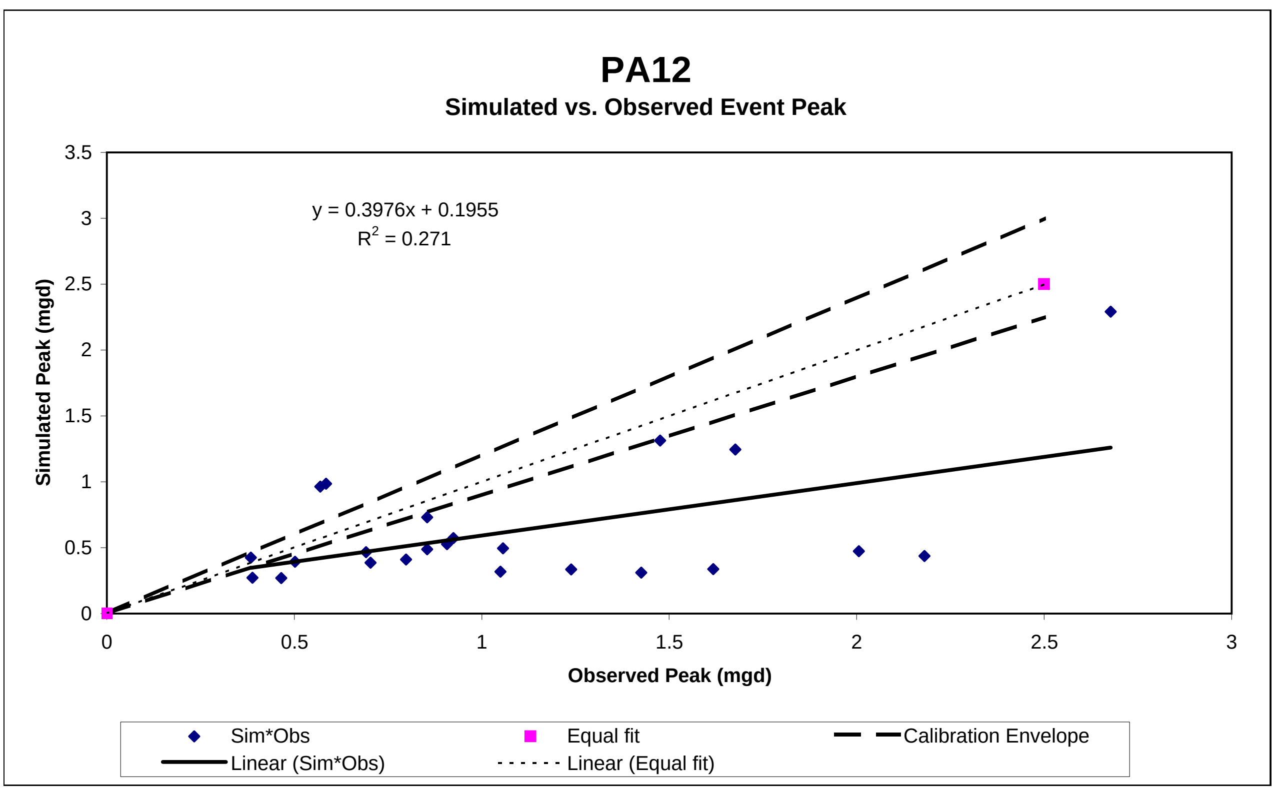

PA11
Simulated vs. Observed Event Volume
y = 0.8738x + 0.4269
R^2 = 0.704
Simulated Volume (mgd)
Observed Volume (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)


PA11
Simulated vs. Observed Event Peak
y = 0.6939x + 0.4131
R^2 = 0.4496
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

Storm Events	PA12								
	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	0.23	0.381	66%	0.585	0.985	68%	0.927	0.5	-0.427
May 14, 2006									
June 2, 2006	0.18	0.319	77%	0.569	0.964	69%	0.534	0.496	-0.038
June 19, 2006									
June 24, 2006									
June 25, 2006	4.995	1.206	-76%	2.677	2.291	-14%	1.154	0.902	-0.252
July 5, 2006	2.37	0.755	-68%	1.676	1.246	-26%	1.628	0.587	-1.041
July 22, 2006	0.491	0.441	-10%	0.854	0.73	-15%	0.645	0.444	-0.201
August 7, 2006	0.339	0.395	17%	0.384	0.424	10%	0.376	0.359	-0.017
September 1, 2006	0.688	0.612	-11%	0.854	0.488	-43%	0.438	0.379	-0.059
September 5, 2006									
September 14, 2006	0.631	0.561	-11%	0.703	0.386	-45%	0.383	0.347	-0.036
September 28, 2006	0.451	0.404	-10%	0.907	0.527	-42%	0.471	0.39	-0.081
October 5, 2006	0.855	0.57	-33%	0.798	0.409	-49%	0.395	0.355	-0.040
October 17, 2006	0.464	0.418	-10%	2.181	0.438	-80%	0.438	0.363	-0.075
October 19, 2006									
October 27, 2006	0.689	0.508	-26%	1.057	0.494	-53%	0.596	0.38	-0.216
November 7, 2006	0.818	0.458	-44%	2.006	0.474	-76%	0.471	0.374	-0.097
November 16, 2006	0.699	0.564	-19%	1.476	1.312	-11%	3.817	0.608	-3.209
November 22, 2006	0.54	0.403	-25%	1.617	0.338	-79%	0.424	0.331	-0.093
December 22, 2006	0.601	0.453	-25%	1.238	0.336	-73%	0.486	0.331	-0.155
January 1, 2007	0.394	0.356	-10%	0.502	0.393	-22%	0.507	0.35	-0.157
January 7, 2007	0.728	0.514	-29%	1.425	0.31	-78%	0.52	0.322	-0.198
March 1, 2007	0.709	0.515	-27%	1.05	0.319	-70%	0.505	0.325	-0.180
March 15, 2007	0.950	0.607	-36%	0.691	0.467	-32%	0.552	0.372	-0.180
March 23, 2007									
April 4, 2007	0.292	0.332	14%	0.388	0.272	-30%	0.399	0.308	-0.091
April 11, 2007	0.401	0.402	0%	0.465	0.27	-42%	0.442	0.305	-0.137
April 14, 2007	1.03	0.814	-21%	0.924	0.574	-38%	0.567	0.403	-0.164

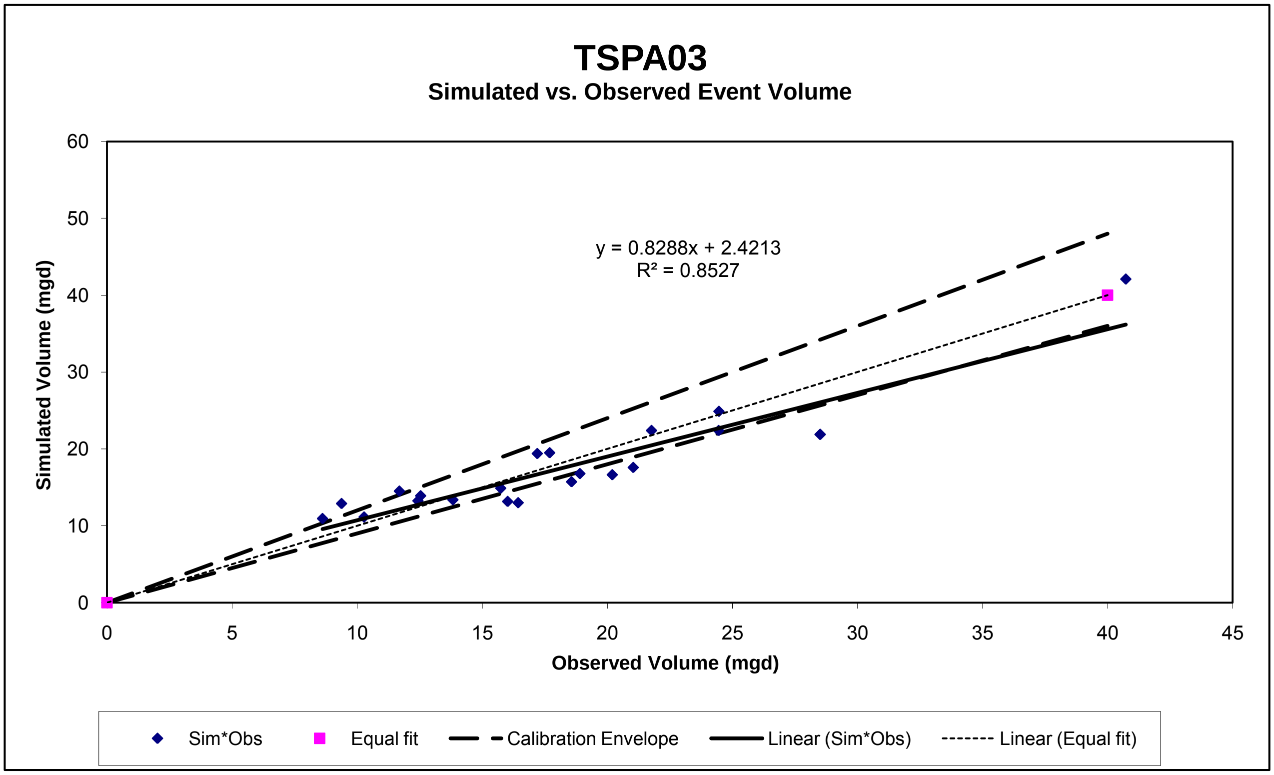


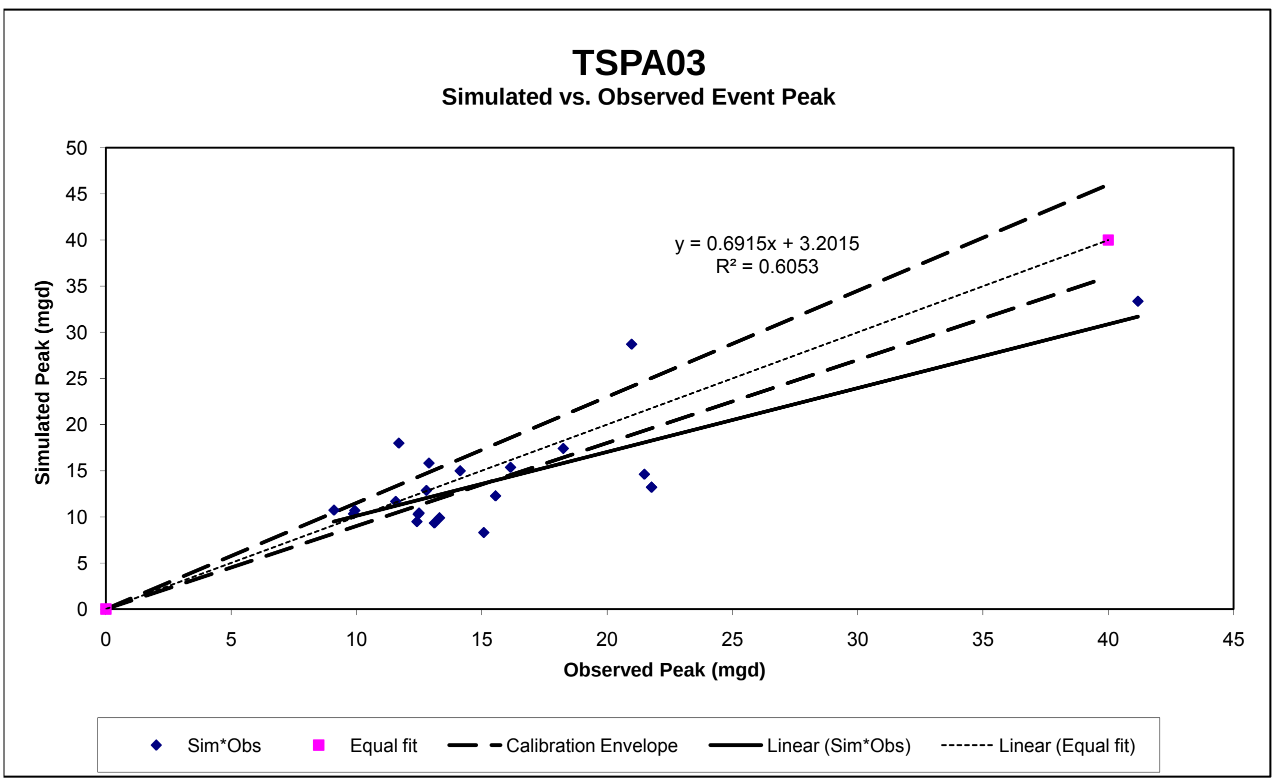
PA12
Simulated vs. Observed Event Volume
y = 0.1774x + 0.3704
R2 = 0.8301
Simulated Volume (mgd)
Observed Volume (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
0
1
2
3
4
5
6
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)



PA12
Simulated vs. Observed Event Peak
y = 0.3976x + 0.1955
R2 = 0.271
Simulated Peak (mgd)
Observed Peak (mgd)
0
0.5
1
1.5
2
2.5
3
3.5
0
0.5
1
1.5
2
2.5
3
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

	TSPA03								
Storm Events	Volume (mg)(-10% to+20%)			Peak Flow (mgd)(-10%to+25%)			Depth (ft.)(-0.25'to+0.5')		
	Obs.	Sim.	% Difference	Obs.	Sim.	% Difference	Obs.	Sim.	Difference
May 11, 2006	9.381	12.896	37%	11.687	17.991	54%	1.94	3.383	1.443
May 14, 2006									
June 2, 2006	8.619	10.944	27%	12.889	15.826	23%	1.827	1.756	-0.071
June 19, 2006									
June 24, 2006									
June 25, 2006	40.73	42.091	3%	20.978	28.706	37%	4.333	3.428	-0.905
July 5, 2006	24.466	24.887	2%	18.25	17.414	-5%	3.117	2.937	-0.180
July 22, 2006	12.542	13.907	11%	9.878	10.335	5%	2.575	1.464	-1.111
August 7, 2006	11.692	14.516	24%	14.135	14.987	6%	4.368	1.687	-2.681
September 1, 2006	21.771	22.398	3%	16.145	15.372	-5%	3.159	1.708	-1.451
September 5, 2006									
September 14, 2006	17.699	19.499	10%	11.563	11.679	1%	2.614	1.526	-1.088
September 28, 2006	12.434	13.25	7%	9.929	10.694	8%	3.052	1.476	-1.576
October 5, 2006	17.204	19.398	13%	12.788	12.869	1%	1.878	1.577	-0.301
October 17, 2006	13.833	13.385	-3%	12.493	10.416	-17%	2.08	1.464	-0.616
October 19, 2006									
October 27, 2006	21.04	17.588	-16%	21.488	14.623	-32%	2.647	1.704	-0.943
November 7, 2006	18.574	15.725	-15%	15.547	12.273	-21%	2.384	1.548	-0.836
November 16, 2006	24.454	22.394	-8%	41.187	33.36	-19%	7.543	3.764	-3.779
November 22, 2006	16.02	13.167	-18%	13.31	9.899	-26%	2.012	1.44	-0.572
December 22, 2006	15.743	14.894	-5%	12.409	9.49	-24%	1.883	1.426	-0.457
January 1, 2007	28.511	21.888	-23%	21.773	13.217	-39%	2.599	1.594	-1.005
January 7, 2007	20.202	16.642	-18%	13.106	9.337	-29%	1.931	1.42	-0.511
March 1, 2007	18.908	16.791	-11%	12.461	10.293	-17%	2.089	1.458	-0.631
March 15, 2007	28.511	21.888	-23%	21.773	13.217	-39%	2.599	1.594	-1.005
March 23, 2007									
April 4, 2007	10.281	11.146	8%	9.099	10.731	18%	1.693	4.422	2.729
April 11, 2007	16.44	13.003	-21%	15.078	8.308	-45%	2.119	1.377	-0.742
April 14, 2007									


TSPA03
Simulated vs. Observed Event Volume
y = 0.8288x + 2.4213
R² = 0.8527
Simulated Volume (mgd)
Observed Volume (mgd)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
40
45
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)


TSPA03
Simulated vs. Observed Event Peak
y = 0.6915x + 3.2015
R² = 0.6053
Simulated Peak (mgd)
Observed Peak (mgd)
0
5
10
15
20
25
30
35
40
45
50
0
5
10
15
20
25
30
35
40
45
Sim*Obs
Equal fit
Calibration Envelope
Linear (Sim*Obs)
Linear (Equal fit)

FIGURES

PATAPSCO SEWERSHED

LEGEND

SEWERSHED BOUNDARY
PUMPING STATION
WASTEWATER TREATMENT PLANT
GRAVITY INTERCEPTOR
SOUTHWEST DIVERSION
FORCE MAIN

CITY OF BALTIMORE
DEPARTMENT OF PUBLIC WORKS
BUREAU OF ENGINEERING

E.P.A. CONSENT DECREE NO. JFM-02-1524

PATAPSCO COLLECTION SYSTEM EVALUATION
& SEWERSHED PLAN PROJECT 1041

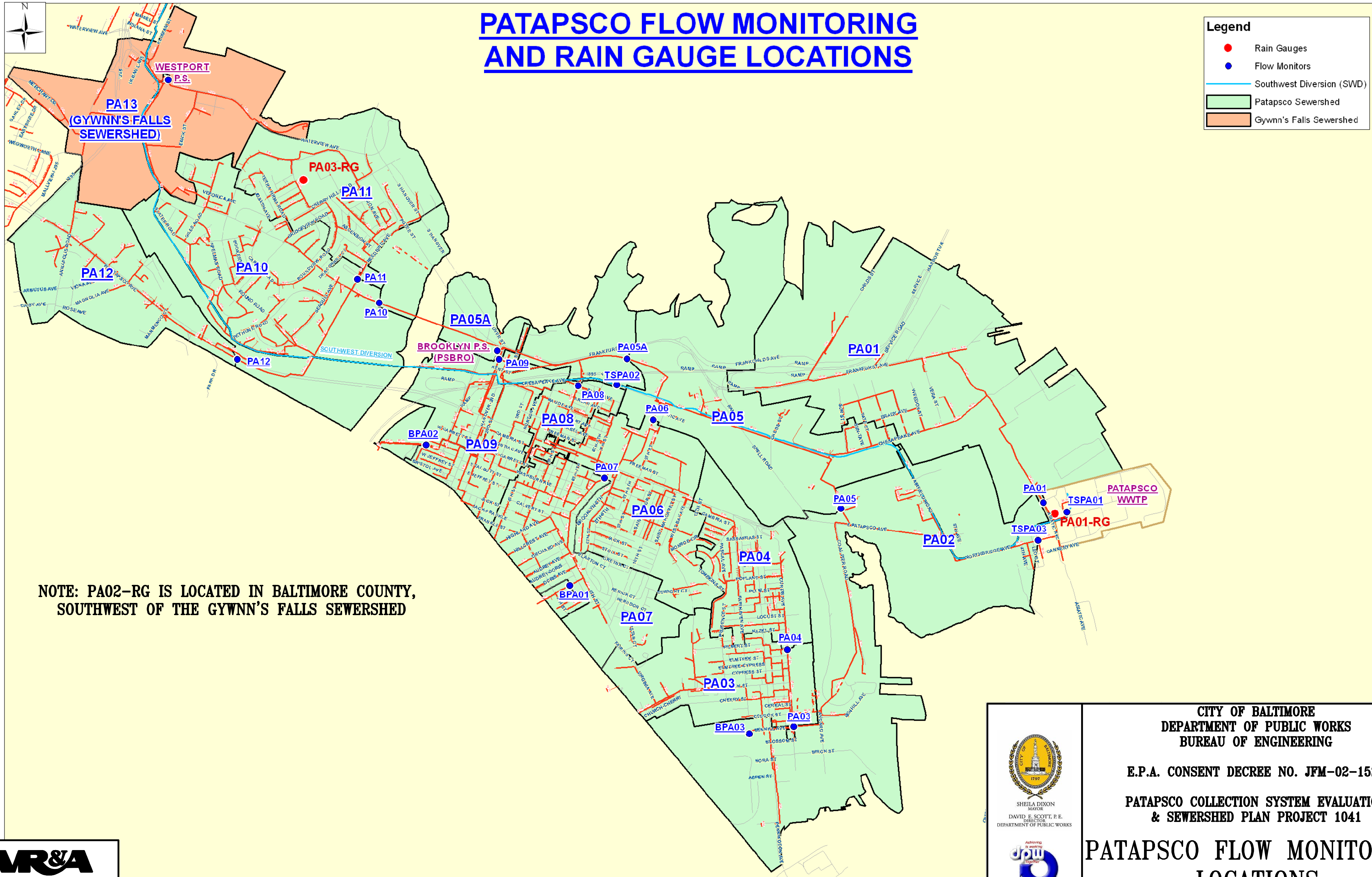
PATAPSCO SEWERSHED
AND SURROUNDING AREA

SHEILA DIXON
MAYOR
DAVID E. SCOTT, P.E.
DIRECTOR
DEPARTMENT OF PUBLIC WORKS

DATE: November 2009 FIGURE: 1

WR&A

M:\00jmb\patapsco sewer shed map\patapsco sewer shed.dgn



WR&A
WHITMAN, REQUARDT & ASSOCIATES, LLP

SHEILA DIXON
MAYOR
DAVID E. SCOTT, P.E.
DIRECTOR
DEPARTMENT OF PUBLIC WORKS

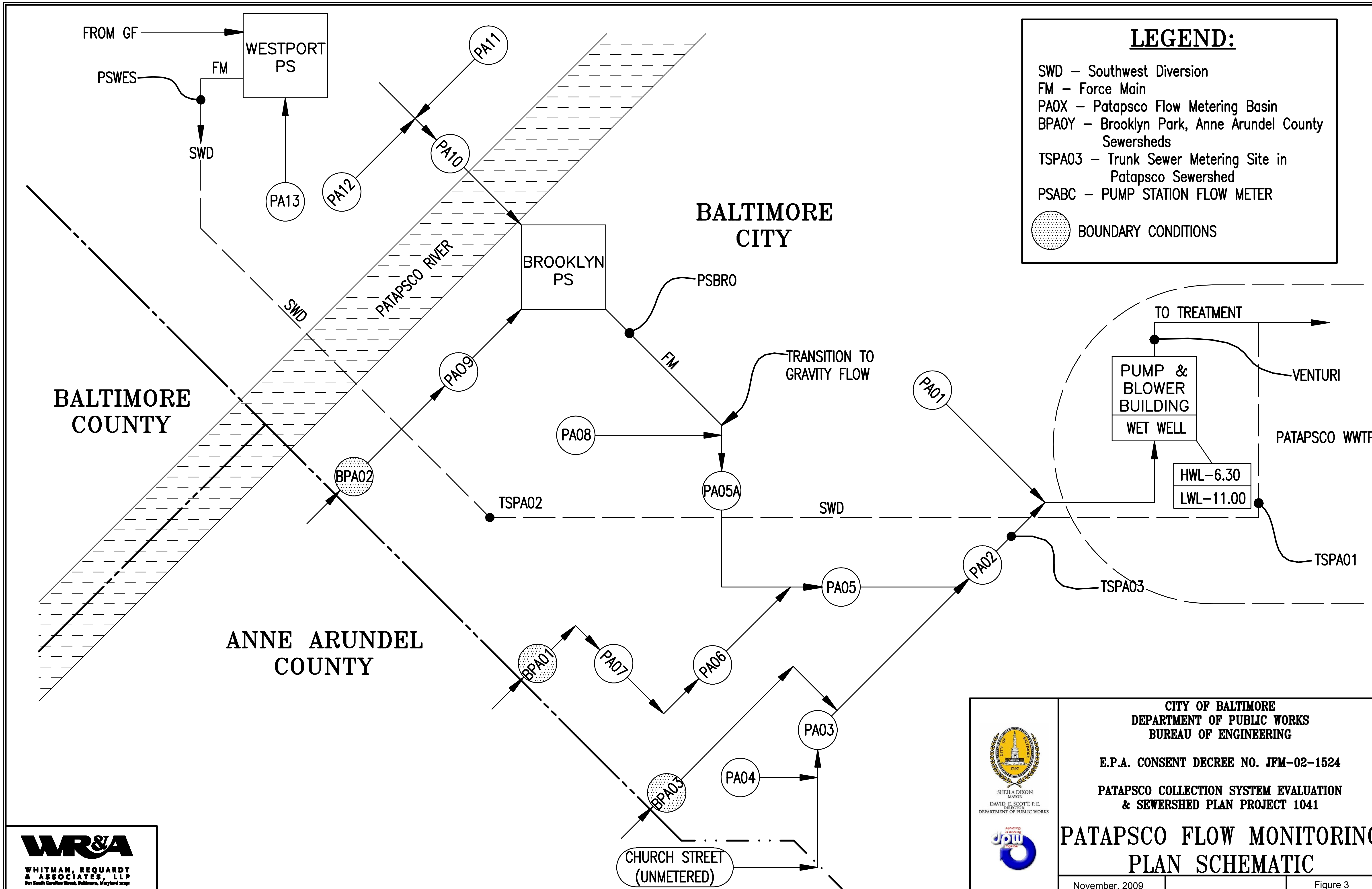
CITY OF BALTIMORE
DEPARTMENT OF PUBLIC WORKS
BUREAU OF ENGINEERING

E.P.A. CONSENT DECREE NO. JFM-02-1524

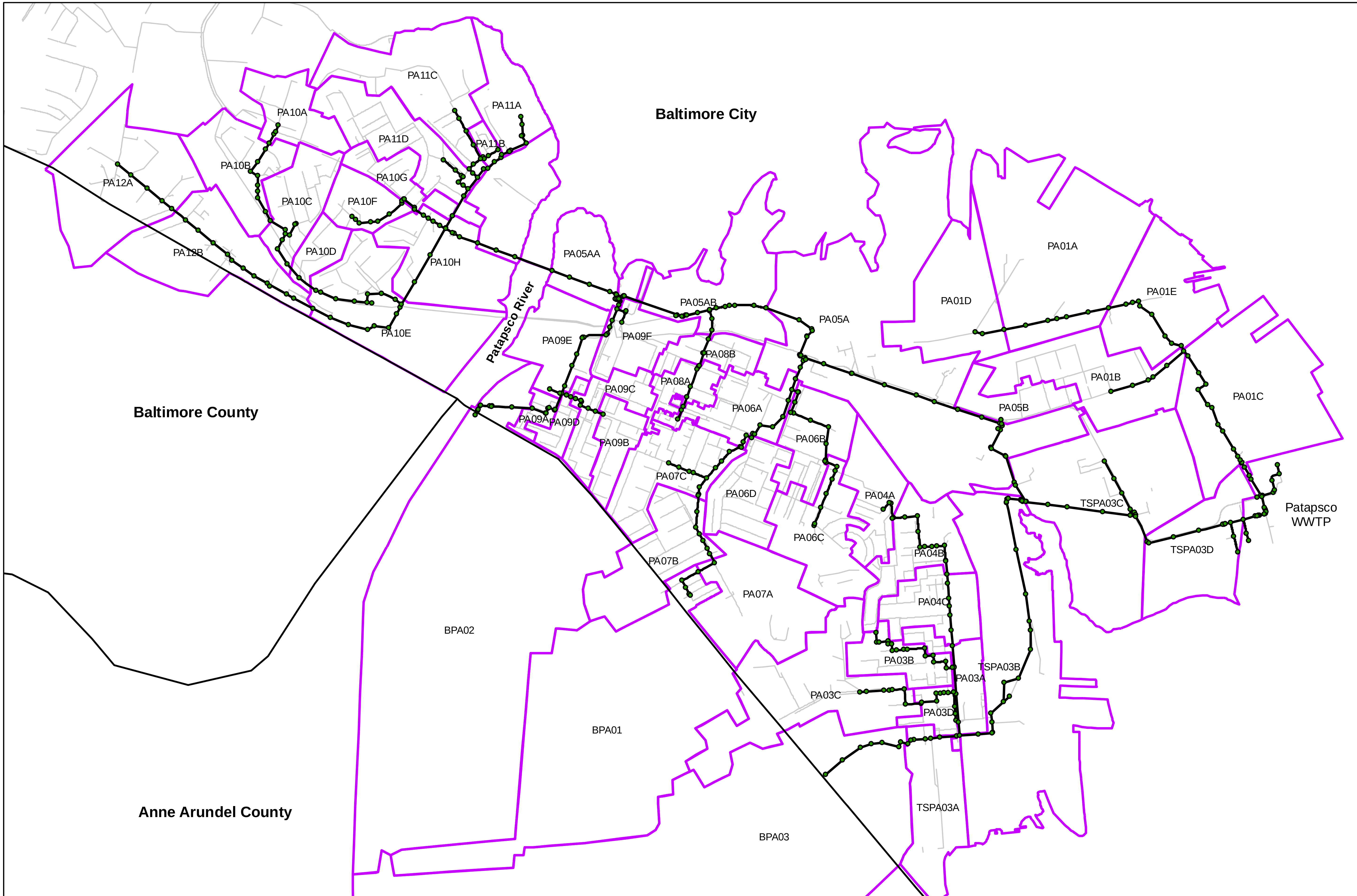
PATAPSCO COLLECTION SYSTEM EVALUATION
& SEWERSHED PLAN PROJECT 1041

PATAPSCO FLOW MONITORING LOCATIONS

November, 2009		Figure 2



LEGEND:
SWD – Southwest Diversion
FM – Force Main
PA0X – Patapsco Flow Metering Basin
BPA0Y – Brooklyn Park, Anne Arundel County Sewersheds
TSPA03 – Trunk Sewer Metering Site in Patapsco Sewershed
PSABC – PUMP STATION FLOW METER
BOUNDARY CONDITIONS
FROM GF
WESTPORT PS
FM
PSWES
SWD
PA13
PA12
PA11
PA10
PATAPSCO RIVER
SWD
BROOKLYN PS
PSBRO
FM
BALTIMORE CITY
TRANSITION TO GRAVITY FLOW
PA08
PA09
PA05A
BALTIMORE COUNTY
BPA02
TSPA02
SWD
PA01
TO TREATMENT
PUMP & BLOWER BUILDING
WET WELL
VENTURI
PATAPSCO WWTP
HWL–6.30
LWL–11.00
TSPA01
PA02
TSPA03
PA05
ANNE ARUNDEL COUNTY
BPA01
PA07
PA06
PA03
PA04
BPA03
CHURCH STREET (UNMETERED)
WR&A
WHITMAN, REQUARDT & ASSOCIATES, LLP
CITY OF BALTIMORE
SHEILA DIXON MAYOR
DAVID E. SCOTT, P.E. DIRECTOR DEPARTMENT OF PUBLIC WORKS
CITY OF BALTIMORE
DEPARTMENT OF PUBLIC WORKS
BUREAU OF ENGINEERING
E.P.A. CONSENT DECREE NO. JFM-02-1524
PATAPSCO COLLECTION SYSTEM EVALUATION & SEWERSHED PLAN PROJECT 1041
PATAPSCO FLOW MONITORING PLAN SCHEMATIC
November, 2009
Figure 3



NOVEMBER 2009
1 inch equals 1,625 feet

Patapsco Sewershed Sub-Catchments

Project 1041 - Patapsco Collection System Evaluation & Sewershed Plan

FIGURE 4

ATTACHMENTS ON CD